PASSIVE SOLAR FOR URBAN TENEMENT HOUSING:
Case Study and Retrofit Design for West-Berlin

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Abstract

Studies about residential passive solar heating have been conducted in many countries, mostly dealing with new or existing single family houses and nearly unlimited access to the sun. Only a few studies are related to residential projects that use passive solar in an urban contextand must cope with limited solar access, fixed city layouts, and contrictive building laws (1,2,3,4).

Multifamily housing in German cities accounts for a major portion of the existing building stock. A range of German energy standards try to enforce the improvement of old and poorly insulated structures but these efforts only support conservation. As yet there is no initiative to seek optimal use of available solar energies.

The heat loss in multifamily housing is already reduced to a significant degree: only a small number of weather walls and windows create actual heat losses, and internal gains act as beneficial heat sources which lower the demand for space heat. With increased use of solar energy, the usual 8 1/2 month heating period could be substantially shortened. Calculations included in this work show the potential for reducing the annual heating season to less than three months.

Case studies of two tenement building types generic to the city of Berlin describe the existing situation in Germany and explore possible approaches for improving the use of passive solar energy by combining new and innovative materials with the existing building stock.

All the factors related to climatic responsible design under local conditions are explained in a step-by-step procedure suitable for use by any architectural office concerned with using passive solar energy in an urban context.

Thesis Supervisor: Timothy E. Johnson

Title: Principal Research Associate

Acknowledgements

The initial stimulus to pursue my interests in energy conscious architecture came from Prof. Peter Steiger, TH-Darmstadt. With his support, I successfully applied for a scholarship from the German Academic Exchange Service (DAAD) and thereupon was subjected to the trials and tribulations of the Master of Science in Architectural Studies program at MIT.

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Additional thanks to my editors Harry Altschuler, James A. Moore, and Bill Gilchrist, without whom the reader would have to know German in order to understand "my" English.

Saving the best for last: the inspiration from my wife Gabi sustained me during the long time of separation. When she joined me in Cambridge for the final months, she placed the full range of her architectural expertise at my disposal. It was far more important, however, just to have her by my side as I completed this last step in my matriculation. She arrived in time to soothe my last minute frustrations with her warmth, her intelligence, her friendship, her love. She turned what could have easily have been a mere academic obligation into the highpoint of my stay in Boston by sharing the experience, as we have shared so many others.

This thesis is dedicated to Gabi, with love.

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Introduction

One of the most difficult challenges ahead in the USA as well as in West-Germany is improving the energy efficiency of existing building structures. The majority of the German building stock that will be in use in the year 2000 are already standing, and unless their high energy consumption is curtailed they will continue to be a major source of wasted energy well into the next century.
For many peaople, particularly low-income individuals without the financial resources to buy new energy-efficient homes or condominiums, this is a vital issue.

Unfortunately the need to retrofit existing buildings with solar and conservation measures has received almost no attention until recently. The general opinion is: "Germany doesn't receive enough solar irradiation to allow passiv solar applications, particularly in cities!" But with newly developed building materials in connection with conservation techniques can transform buildings from heat-wasters to heat-traps.

Only 1 percent of the buildings in West-Germany are torn down in a given year, and annual construction accounts on average for 2 to 3 percent of the building stock. So even if all the homes and commercial structures built between now and the year 2000 were solar buildings, they would constitute only about one forth of the total at the turn of the century. Relying on this hypothetical process for a complete transformation of the building stock would take several additional decades.

One possible strategy would be to accelerate the replacement of old inefficient buildings, but the cost would be staggering - it even might be counterproductive. Making the existing buildings more energy-efficient is thus the logical alternative.

Though it is a more difficult, costly and institutionally complex process than starting from scratch at design stage, potential energy savings from such a program are probably greater than for the most ambitious new construction programs.

This thesis will explore ways to convert conventional residential buildings located in the city of Berlin into more energy efficient ones. Conservation measures, passive solar retrofit and reorganisation of floorplan, will be used in connection with new architectural finish materials to exploit the available solar energy to highest feasible degree under presently existing constraints.

Studying "what can be done?" in a retrofit context is to study one of housing's most difficult physical situations where there are many constraints and building restrictions acting together, limiting what can be done.

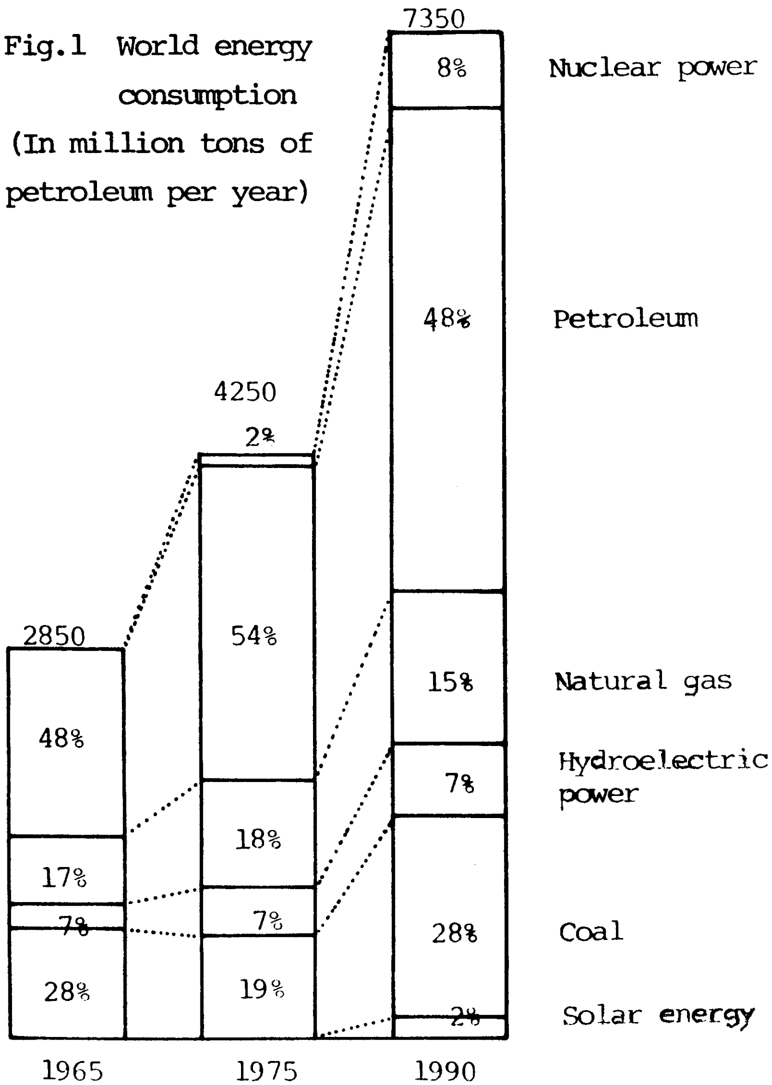
The final result of this thesis shows that by carefully redesigning existing building structures and building layouts, by using new and innovative building materials, and by taking full advantage of the available solar energy, remarkable improvements in the overall building energy performance can be attained.

These measures are taken to reduce the energy consumption of buildings and to enhance the thermal comfort conditions for the inhabitants.

CHAPTER 1

ENERGY SITUATION IN WEST - GERMANY

Fig.1 World energy consumption (In million tons of petroleum per year)



Source: EXXON quoted by Der Spiegel Heft 47/1978

World Energy Consumption

So far, the development of the industrialized countries was possible because of the seemingly unlimited availability of sources of energy. As a result of the continuing and ever increasing energy requirements of the industrialized countries and the growing backlog demand of the developing world, the exploitable reserves of fossil sources of energy which developed over many millions of years will be exhausted in a matter of a few decades. Fig. 1 shows the energy consumption (1965,1975,1990) of the world (without communist states) divided as to its proportional energy sources.

As a result of the growing recognition that presently dominating energy sources, i.e., oil, natural gas and coal, will no longer be sufficient to meet the world-wide demand even in the foreseeable future, the exploration and development of new sources of energy as well as efficient and economical utilization of existing sources has been a major goal of each country in the world.

Energy is the essential motor of our life and the energy crisis in 1973 again emphasized the importance of guaranteed continuity of energy supply in the medium to long term.
Shortages (=crisis) in the energy supply of all major industrialized nations - including West-Germany - are due to an unbalanced energy supply which makes it impossible to substitute a shortage in one source through oversupply of another source.

Development of Primary Energy Consumption in West-Germany

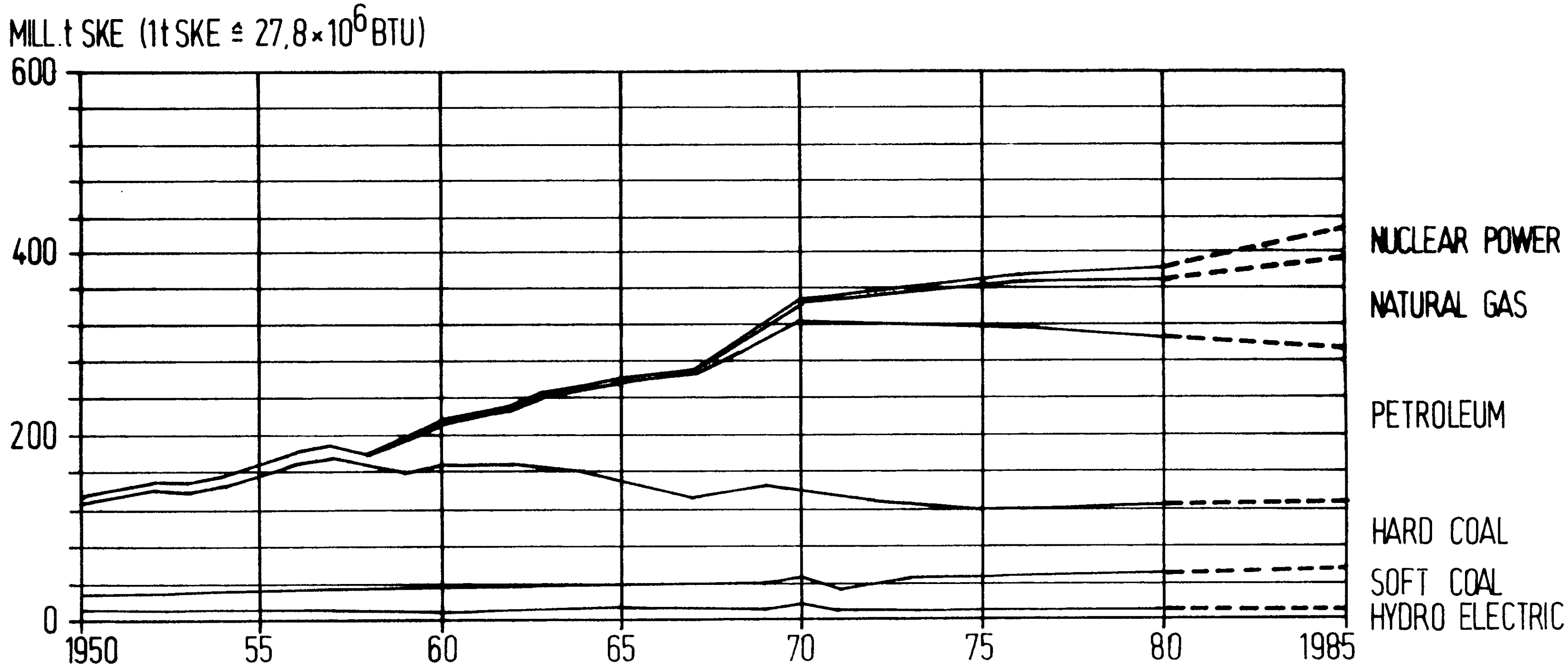
The industrial development of a country is mainly determined by the availability of inexpensive energy.
After the 2nd World War, Germany's own coal resources made the rapid rehabilitation of its industry possible and were the basis for the so-called "Wirtschaftswunder."

Fig. 2 shows the dominance of hard coal as the main energy source until the beginning of the early sixties. The following change in the supply structure is particularly interesting: The increase was not entirely met by cheaper oil and gas - in fact even the slightest decrease of coal production during this period was compensated by oil and gas. Further, it is evident that nuclear energy amounts to only 2% (1976) of total primary energy. The diagram shows the economic problems which have been created. [5]

Oil accounted in 1976 for 53% of primary energy supply and is imported almost entirely (1976: 96%) from Arab countries - a situation resulting in a high degree of economic and political dependence. Today the problem of oil supply is not one of quantity but one of price and balance of payments. Unitl a few years ago the price of oil was mainly determined by production and transport costs. Since then the oil producing countries have recognized that they can ask a price for oil which is mainly limited by the price of the cheapest alternative. During the seventies natural gas gained an important share (16.5% in 1980) of the German energy market in an effort to reduce West-Germany's dependence on petroleum.
But because of Germany's own limited sources of gas (in 1980 almost 70% were imported), this only entailed a shift from one dependency to another.

Other alternatives such as coal and solar energy are available but their utilization cannot be quickly implemented.

Fig.2 Development of the primary energy consumption in West-Germany



Future Development of Primary Energy Consumption of West-Germany

Predictions vary as to how the actual consumption-picture will appear in the distant future. No single forecast can encompass all of the uncertainties of the next twenty years. In 1977 the Workshop on Alternative Energy Strategies (WAES) published the third volume in a series of technical reports, called "Energy Supply-Demand

Integrations to the Year 2000." For all western industrialized countries the Workshop identified a range of different but plausible futures (called a "scenario" approach). Scenarios are not forecasts: they are chosen to span a wide range of possible futures that lead to different estimates of energy demand and supply. Excerpts of this study are presented below:

"Primary energy demand of the FRG in 2000, given the explicit WAES scenario assumptions, is estimated to range from about 580 to 690 million tons of coal equivalent."

"The relative contribution of oil continues to decrease through 2000. Natural gas has almost reached its maximum share in 1985. When gasification becomes competitive, it cannot adhere to its 1985 share. The nuclear power contribution is increasing relatively in all scenarios. The coal share depends on the size of the nuclear contribution." [6]

The following development in the different types of primary energy may be expected:

With steadily increasing oil production all of the sources will be gradually exhausted, resulting in a supply problem in 25 to 30 years. The only alternative that has been considered up to now and which has received the largest governmental support, nuclear energy, will be required to meet a substantial part of the demand in the near future. For instance in the FRG plans have been made to supply 15% of total energy requirements with nuclear power by 1985. This estimate was done in 1974 (Erste Fortschreibung des Energieprogramms der Bundesregierung vom 7.10.1974). But popular opposition to the construction of nuclear plants is continually growing and in some cases causes delays of years or even termination of projects. It is therefore justifiable to ask whether nuclear power can even meets its expectations (in 1980 its share of primary energy was 3.6%).[7]

Secondary Energy

The losses due to energy conversion (processing, transformation, transmission and distribution) add up to an average of 30-33% of total energy consumption in West-Germany over the last years. After this transformation the final energy sources of electricity

gaseous fuels (natural gas, synthesigas, towngas, etc.

liquid fuels (fuel oil, gasoline, etc.)

solid fuels (coke, lignite briquettes, etc.) and

district heat

can be distributed among the consumers.

Fig.3 shows the energy flow of West-Germany:

Development of Final Energy Consumption in West-Germany

Final energy consumption between 1960 and 1970 climbed at an annual rate of 4.6%, implying that it will double in 16 years. The particular categories of energy use contributed to the total increase in different ways. Final energy consumption of industrial sector grew at an annual rate of

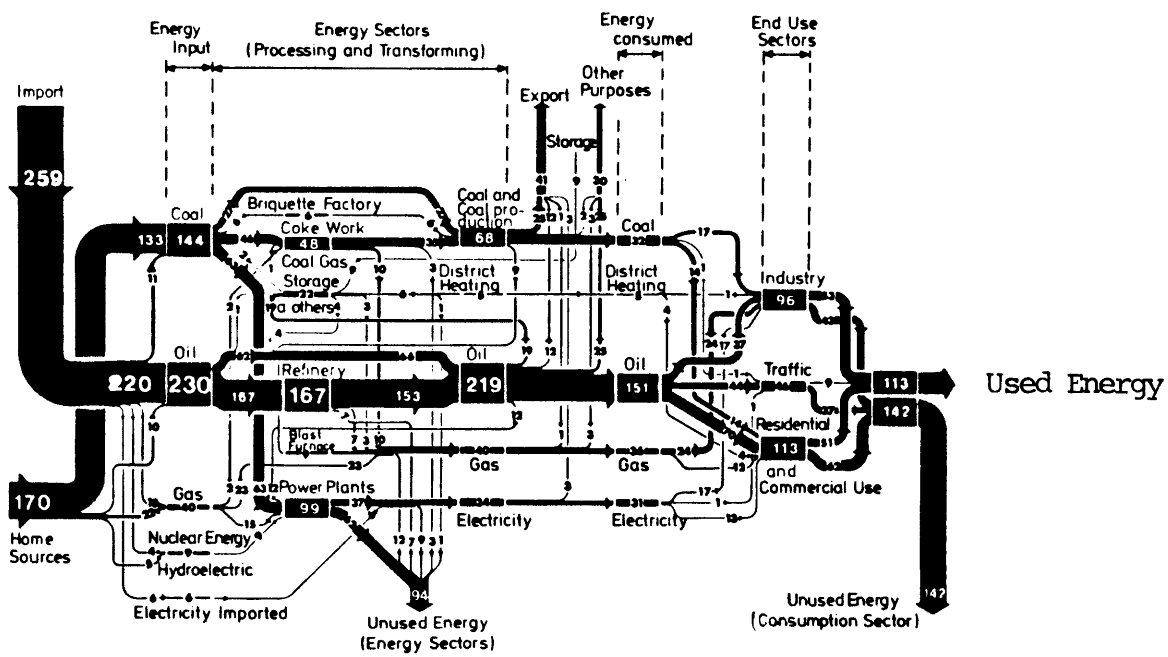


Fig. 3 Energy flow diagram of West Germmany

Source: Stoy,B.: Umschau in Wissenschaft und Technik 73 (1973) only 2.3% (doubling in 30 years). The transportation sector raised its consumption at an annual rate of 5.2% (doubling in 14 years). The rate of energy consumption for the residential and commercial sector soared at the rate of 6.7% per year (doubling in less than 11 years).[8]

A comparison of consumption of final energy in the industrial, transportation and residential and commercial sectors for the years 1960 and 1976 shows an increase in the residential and commercial sector. Its contribution to the consumption of final energy grew from 36% to 44%. The

Primary Energy Consumption (in 10^6 tSKE)	1970		1971		1972		1973		1974		1975		1976		1980	
	SKE	%	SKE	%	SKE	%	SKE	%	SKE	%	SKE	%	SKE	%	SKE	%
Petroleum	178.9	53.1	185.7	54.7	196.9	55.6	209.0	55.2			181.0	52.1	195.9	52.9	187.0	47.8
Hard coal	96.8	28.8	90.3	26.6	114.8	32.4	84.2	22.2			66.5	19.1	70.7	19.1	77.0	19.7
Natural gas	18.3	5.4	24.0	7.1	30.9	8.7	38.6	10.2			48.7	14.0	51.4	13.9	64.5	16.5
Soft coal	30.6	9.1	29.3	8.6			33.1	8.7			34.4	9.9	37.5	10.2	38.5	9.9
Nuclear energy	2.1	0.6	2.0	0.6	3.1	0.9	4.0	1.1			7.1	2.0	7.9	2.1	14.0	3.6
Hydro energy and others	10.1	3.0	8.1	2.4	8.6	2.4	9.7	2.6			10.0	2.9	6.8	1.8	7.5	1.9 0.6
total	336.8	100.0	339.4	100.0	354.3	100.0	378.6	100.0	365.9	100.0	347.7	100.0	370.2	100.0	388.5	100.0
Primary energy use per inhabitant (in SKE)	5.55		5.54		5.74		6.11		5.90		5.62		5.97		6.26	
Secondary Energy Consumption																
Transformation	106.4	31.6	108.3	31.9			124.7	33.1			113.7	32.7	121.6	32.8		
Final energy consumption	230.4	68.4	231.1	68.1			253.9	66.9			234.0	76.3	248.6	67.2		
Final Energy Consumption																
	230.4	100.0	231.1	100.0			253.9	100.0			234.0	100.0	248.6	100.0		
Industry	90.8	39.4	88.4	38.2			95.6	37.7			84.0	35.9	88.3	35.5		
Transportation	39.5	17.2	42.5	18.4			45.8	18.0			46.2	19.7	48.5	19.5		
Residential and commercial	100.1	43.4	100.2	43.4			112.6	44.3			103.8	44.4	112.0	45.0		

Fig.4 Energy Consumption in the Federal Republic of Germany

fraction consumed by the industrial sector dropped from 49% to 35.3%. The development in the 1970's is shown in Fig. 4.

Saving Potential in the Residential and Commercial Sector

Studies initiated by the German Ministry of Research and Technology have shown the largest saving potential to exist in the residential and commercial sector which, as indicated above, also has the highest increment rates in the consumption of final energy. This applies above all to the large area of the supply of low temperature heat, which amounts to roughly 80% of the consumption of final energy in this sector.
If one considers the total consumption of energy, one can say that roughly one half is used to produce temperatures of 100°C or less. In other words: we use high grade chemical energy for applications requiring low-value heat.
This assessment suggests two methods of solution:

1. We should be able to reduce the amount of energy used for heating purposes drastically by making more rational use of it - for instance by improving insulation in buildings. It would be useful to analyse appropriate measures in this direction to see whether they are more economical than the development of new sources of energy.
2. Solar radiation with its low-energy density can be extensively employed in the production of low temperature heat. With further technical development solar radiation should be capable in the near future of providing heating in the domestic and industrial sectors and thus should relieve the burden on other energy forms. This task will be all the easier the more use is made of the first suggestion (improvement in insulation). [7]

Energy Use in the Residential Sector

Most of the energy used in the residential sector (without commercial) is consumed for space heating and hot water production: in 1976 86% for heating, 4.7% for domestic hot water and 4.7% for light and power. In this sector of consumption reseach projects should thus focus on improvements in heat economy.

Heating requirements are different for different building types (Fig. 5):

1. Detached single family house
2. Duplex houses
3. Row houses
4. Multi-family houses

Incentives for improvements in the energy consumtion are higher in the first two types because owner and inhabitant are identical. It is in his own interest to keep down energy costs. The situation is different for rented spaces - likely in types three and four - where the tenant pays the heating bill and not the owner.

Future Development of Final Energy Consumption in the Residential Sector

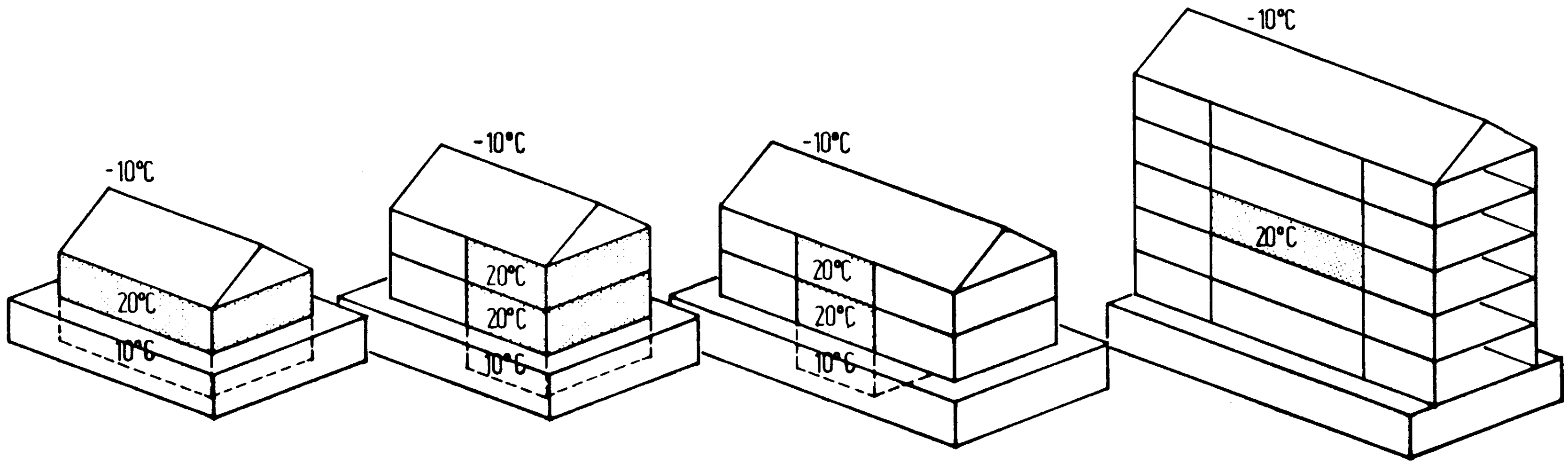
The WAES Report [6] relates future energy consumption patterns closely to the development of energy prices:

"...changes in price relations among fuels because of both higher oil prices and higher electricity prices have a comparably strong impact on residential energy consumption patterns. The negative growth rates of fossil fuel consumption in the residential sector are partly due to the use of more efficient forms of energy such as district heat."

Higher prices will have a major effect on increasing the efficiency of presently dominating heating systems as well as the development of more advanced systems to save energy:

"The distribution of heating systems bv fuel type is influenced heavily by the development of the absolute and relative energy prices. Higher energy prices are assumed to force the development of district heat, electricity and advanced supply systems such as heat pumps and solar energy.

Heat loss is reduced continually up to the year 2000 such that the average standards in 2000 are close to the top standards of 1975. In particular, single family houses are expected to show a relatively large improvement. (note: owner and investor = user)... The same development is assumed for (heating-)system efficiencies. Old systems are replaced and renovated. Thus, the efficiences of modern systems in 1975 are the average efficiencies in 2000." [6]



TYPE 1 TYPE 2 TYPE 3 TYPE 4

ALL TYPES ARE CALCULATED FOR 150 m^2 USABLE FLOORAREA

			Type 1		Type 2		Type 3		Type 4	
	$t_i - t_o = \Delta t$ °C	k-value W/m^2K	area m^2	losses KW/DD	area m^2	losses KW/DD	area m^2	losses KW/DD	area m^2	losses KW/DD
Walls + Windows	20°-(-10°)=30°C	1.5	138	6.21	138	6.21	83	3.74	55	2.48
Ceiling (Roof)	2o°-(-10°)=30°C	0.5	150	2.25	75	1.12	75	1.12	-	-
Basement-ceiling	20° - 10° =10°C	1.0	150	1.50	75	0.75	75	0.75	-	-
		s.H.xAC	volume m^3		volume m^3		volume m^3		volume m^3	
Infiltration	2o°-(-10°)=30°C	.34x.75	412.5	3.16	412.5	3.16	412.5	3.16	412.5	3.16
Total losses				13.12		11.24		8.77		5.64
Losses per m^2				87.5W		75.0W		58.5W		37.5W
				100%		86%		67%		38%

Fig. 5 Energy consumption of different house types

New Sources of Energy

Foreward to Subprogram 3 of the Program for Energy Research and Technologies 1977-1980:

"As a result of the recognition that presently dominating sources of energy, i.e., oil, natural gas and coal, will no longer suffice to meet the worldwide requirement even in the foreseeable future, the development of new sources of energy has for some time been one of the main goals of applied research. As far as other possibilities of exploiting natural resources and methods of energy generation by technical processes are concerned, research is now focused on those sources of energy which can be expected to contribute to the supply of energy under acceptable economic and ecological conditions.

Despite the short time for which this development has been going on, the direct use of solar energy is now very much in the foreground of interest. Especially in Central Europe the use of solar energy for heat generation is a promising possibility, first for the preparation of hot water and, in a next step, also for the supply of space heat to buildings."

Despite these very promising official statements the German government spent in 1980 only 9 Mill. Deutsch Mark for research on alternative energies compared with 40 Mill. DM on coal and oil, and 140 Mill. DM on nuclear energy.[9]

Nevertheless the German government sees the advantages of using more of the available solar energy:

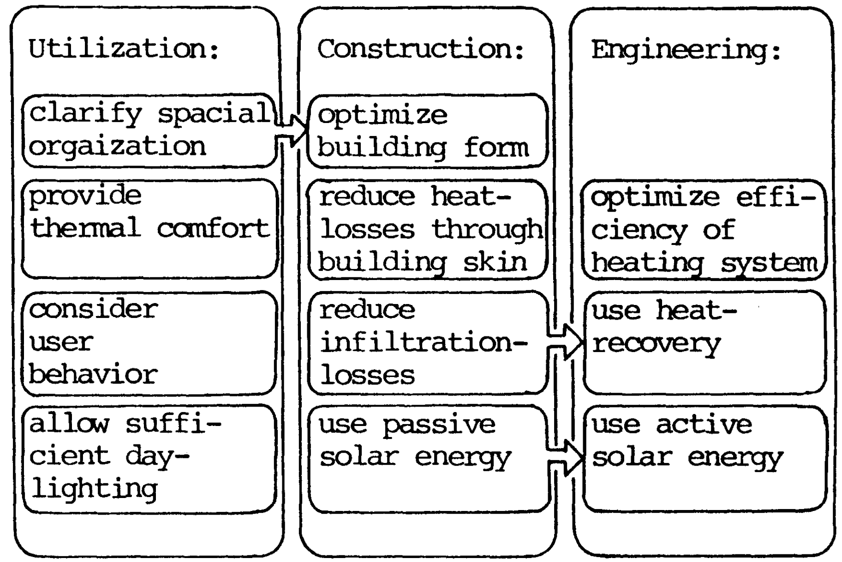
"Solar energy offers the tremendous long term advantages of being independent of earthbound resources and not causing additional thermal or other pollution of the earth, but only a regional change in the energy balance. The amount of energy incident upon the territory of the Federal Republic of Germany corresponds to about 80 times the present use of primary energy. Only a small fraction can be utilized under the technical and economic conditions presently forseeable.
Here are the most important boundary conditions for technical exploitation:

- The low energy density of solar radiation in the Federal Republic of Germany
- Fluctuations in the availability of energy as a function of the time of the day, the weather and the season. Most of these variations are opposed to the variations in energy requirement."[10]

Possibilities for Energy-Savings in Buildings

Utilization:

Proper design of a building should be determined by thermal, acoustic, visual and aesthetic comfort requirements of the user. Therefore his needs and his behavior provide the guidelines for spacial organization patterns, thermal conditions and lighting levels. These needs should be satisfied according to energy-conscious requirements.



Construction:

Helping to meet these requirements is the main task of designing the form and skin of buildings according to local climatic conditions. A given environment, site constraints, economic considerations, building regulations may affect the optimal solution.

Engineering:

The subordinate aspects of the engineering side must assure proper functioning of the building after all previous requirements are fulfilled. This has to be done in a feasible and economical way.

Between these three main areas exists a dense network of interrelations. Any action taken on one side will affect the others as well, either in a positive or negative way. None of these areas can be handled without considering the other areas at the same time.

CHAPTER 2

CLIMATE AND ARCHITECTURE

Climate and Architecture

Passive concepts, wherein the form of the building itself provides heating or cooling, have long been utilized in traditional building designs and construction methods. For centuries, building design in different environments has adapted itself to the given climatological circumstances. Reyner Banham in "The Architecture of the Well-tempered Environment," 1969:

A thick and weighty structure offers better sound-insulation, better thermal insulation and—equally important—better heat storage capacity. This last quality of massive structure has probably played a larger part in rendering European architecture habitable than is commonly acknowledged. The ability of massive structure to absorb and store heat that is being applied to it, and to return that heat to the environment after the heat source has been extinguished, has served European architecture well in two ways: the mass of masonry in a fireplace, chimney-breast and chimney, has served to store the heat of the fire during the day while the fire burns, and to return it slowly to the house during the chill of the night when the fire has burned out.

In more sophisticated forms that use glass as a filter to discriminate between light-energy, which is allowed to pass, and heat energy, whose passage is barred, similar effects of thermal storage are used in the normal green-house, and the whole technique might well be termed the 'Conservative' mode of environmental management, in honour of the 'Conservative Wall' at Chatsworth, devised by that master-environmentalist Sir Joseph Paxton, in 1846.

This conservative mode seems to have become the ingrained norm of European culture, though it has always had to be modified, drastically in humid or tropical climates, less obviously for every-day use, by the 'Selective' mode which employs structure not just to retain desirable environmental conditions, but to admit desirable conditions from outside. Thus a glazed window admits light but not rain, an overhanging roof admits reflected sunlight, but excludes the direct sun, a louvered grille admits ventilating air but excludes visual intrusions.

The increased use of energy in the twentieth century, the evolution of the sealed interior environment and sophisticated mechanical environmental controls made it possible to transplant materials and forms to all corners of the world. Amazingly enough, 26 years ago James Marston Fitch wrote the following sentences:

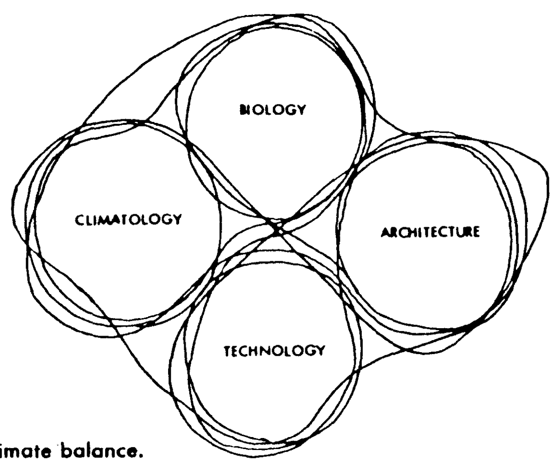
"... with the rapid industrialization and urbanization of the Western world, there is a growing tendency to minimize or ignore the importance and complexity of the natural environment. Not only is the modern architect quite removed from any direct experience with climatic and geographic cause-and-effect; he is also quite persuaded that they "don't matter any more." Yet the poor performance of most modern buildings is impressive evidence to the contrary."[11]

Five years later nothing had changed and James Fitch was still complaining:

"A central reason for his failure lies in consistent underestimation of the environmental forces that play upon his buildings and cities, and consistent overestimation of his own technological capacities." [12]

As we can see the situation is still unchanged nowadays. Once more a quotation from Reyner Banham:

"It would have been apparent long ago that the art and business of creating buildings is not divisible into two intellectually separate parts - structures, on the one hand, and on the other mechanical services. Even if industrial habit and contract law appear to impose such a division, it remains false."



Interlocking fields of climate balance.

Passive Solar Design

Passive design implies building forms that generate conditions of comfort and satisfy operational needs without resorting to mechanical means. These designs take advantage of natural physical properties - absorption, radiation, reflectance, conductance and convection - to collect, store and transmit heat from the sun and to provide natural ventilation.
Active systems, in a word, are primarily engineering solutions, while passive systems are primarily architectural. (Selma A. Newburgh) [13]

The rise of environmental consciousness as well as the shock of awakening provoked by the energy crisis led to the rediscovery of how to build in response to local conditions. When dealing with the thermal behavior of inhabitable enclosures architects have to cope with four basic elements: outside microclimate, structure, inside space and occupant.
Even if the occupant is one of the more unpredictable factors in a passively operated house his response and understanding of the passive

system is crucial for its function. This would expand Selma A. Newburgh's quotation to: Passive systems are primarily solutions requiring human activity, while active systems require primarily mechanical activity.

Planners and architects - as well as occupants - have to learn again how to make use of given climatical conditions. However the raw knowledge of weather data provided by weather services does not automatically lead to proper and correct application. Data have to be processed and evaluated according to demands imposed by the practice of building experts. In Germany initial efforts to install this connection between meteorologists and building experts were made by R. Reidat in Hamburg and Prof. Reiher in Stuttgart in the 1950's.

The aim of the passive solar design philosophy is always to tame the annual and diurnal fluctuations in temperature as well as to raise sub-average temperatures to within comfort standards.[14]

Two sets of climatic data are needed to conduct analysis of passive systems:

The first is the "normals" of daily temperatures for each month of the year. These are required to calculate monthly heating degree days, a figure to describe the building's heat consumption. The second set of climatic data consists of solar insolation data. These are required to determine the monthly solar gains as part of the energy-balance of a building. To assess whether or not the energy collection space is in danger to overheat, the designer also needs information about maximum air temperatures. Minimum air temperatures are needed to determine the required auxiliary heat as well as to calculate vapor diffusion through walls. Under certain conditions these two sets of climatic data have to be linked to wind velocity and sometimes to humidity - in case where latent heat transfer and vapor diffusion problems have to be considered. The analysis of this data involves a comparison of the data describing the conditions which exist with conditions that are required (= the ranges of environmental conditions that feel comfortable for the inhabitants of a building).

The following pages will give a short overview over the general weather conditions of West-Germany.

Knowledge of the climatic zone to which a town or settlement belongs and possession of published regional climatic data does not eliminate the need for careful investigation of site climatic conditions. It does, however, usually provide enough information for the designer to make a preliminary assessment of the climate and may be sufficient to form the basis of sketch designs. Every city, town or village and even a precinct in a town may have its own climate, slightly different from the climate described for the region - the macroclimate. Information published by the nearest meteorological observatory may be a useful guide to the climate of the site, but is seldom sufficient in accuracy as conditions can vary considerably within a short distance from the point of observation.

General Weather Conditions in West-Germany

For the area of West-Germany four main climatic provinces can be defined by their geographic latitude, their distance from the sea and their altitude:

(1) the coastal region and the lowlands in the northern part of Germany

(2) the German highlands

(3) the Alpine foreland

(4) the Alps

Global Radiation

As far as global radiation is concerned we too can use this classification. [15]

(1) Global radiation in the coastal region and the lowlands in the North.

The annual amount of solar radiation runs up to 335-420 $kJ/cm^2 year$. The nearness of the North Sea and the Baltic attributes genuine maritime features to the northern and western parts of the lowlands, whereas the interior clearly is subject to increasing continentality as one proceeds eastwards. Low pressure systems from the West bring air masses of polar and subpolar origin. After their long way across the ocean they contain much moisture, especially in their lower layers. Reaching the continental area on their way from West to East, the airmasses rise due to different roughness of the surface and different temperature levels. The rising air gets colder and moisture condenses as clouds. Therefore we can observe a high radiation level (420 kJ/cm^{2}year [16]) in the coastal strip (10-30 km) and a decreasing lower radiation level further south and eastwards (335-355 kJ/cm^{2}year in Hamburg). The differences in the seasonal variation of temperature and moisture between land and sea affects the occurence of fog: the maximum probability for fog over the continent is to be expected in autumn due to radiational cooling at night, whereas the coastal area has a main maximum of fog frequency in December and a secondary in March.

(2) the German highlands:

The highlands lying south of the northern lowlands experience a decline of the maritime influence towards the South, while the influence of high-pressure conditions is felt more and more, especially in winter. For the westerly flow of airmasses the highlands form a barrier which leads to increasing cloud formation. This natural reduction of radiation is intensified by problems of air pollution in the industrial centers (Rhine-Ruhr area). The mean annual radiation level rarely exceeds 315 kJ/cm^{2}year (Bergisches Land). On the southern lee-side of the highlands the radiation level climbs again to 355 kJ/cm^2 year.

(3) the Alpine foreland:

The climate of the northern Alpine foreland is mainly controlled by the influence of the Alps. The higher annual isolation level of 375-420 kJ/cm^{2}year is not only due to the geographical effect (southern part of Germany and higher altitude), but is also due to the special clima-

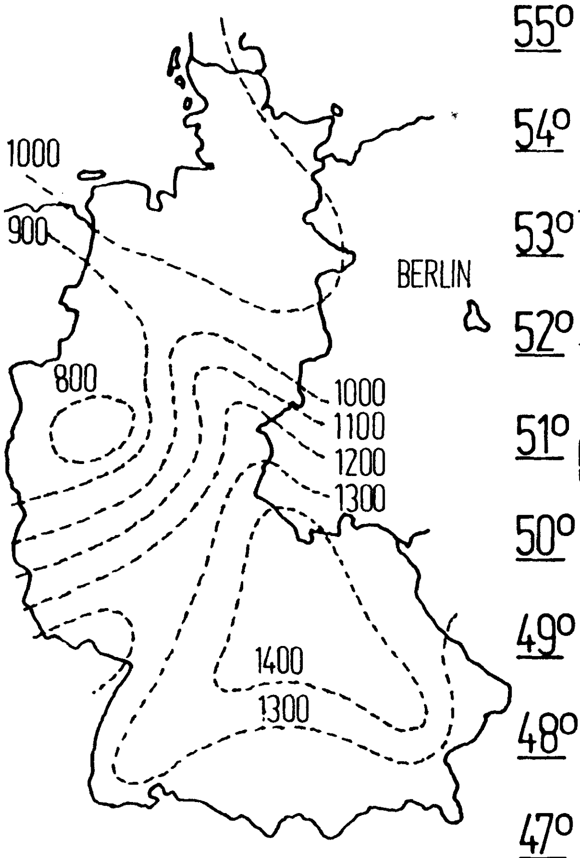


Fig.6
Mean daily amounts of direct solar irradiation for June 1979 in J/cm^2

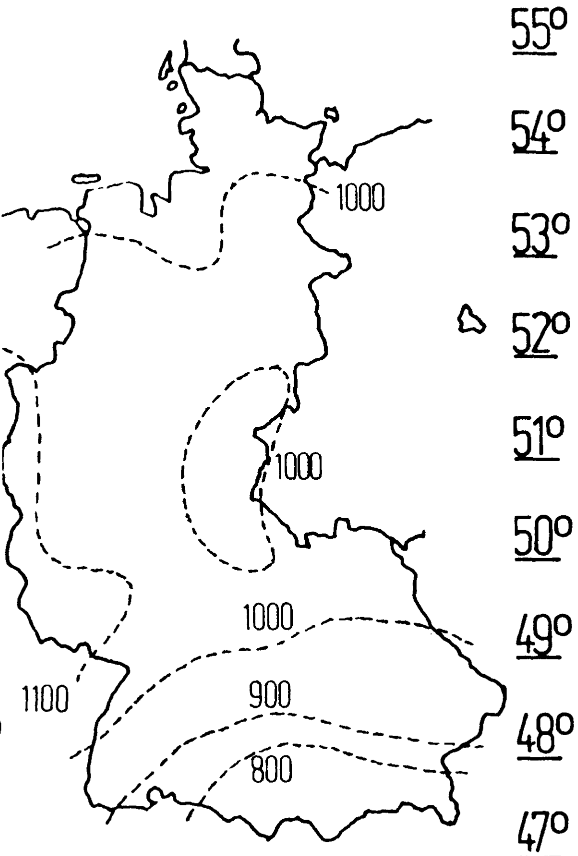


Fig.7
Mean daily amounts of diffuse solar irradiation for June 1979 in J/cm^2

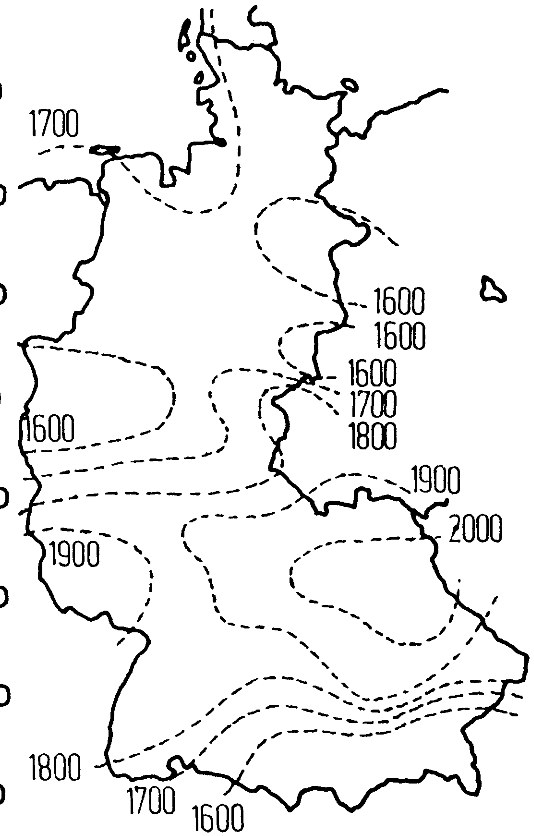


Fig.8
Mean daily amounts of global solar irradiation for June 1979 in J/cm^2

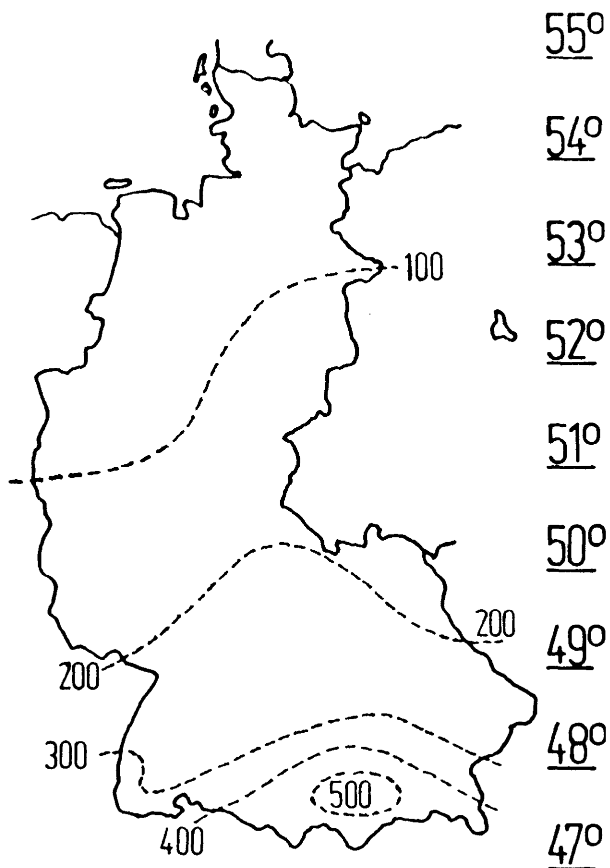


Fig. 9
Mean daily amounts of direct solar irradiation for Dec.1979 in J/cm^2

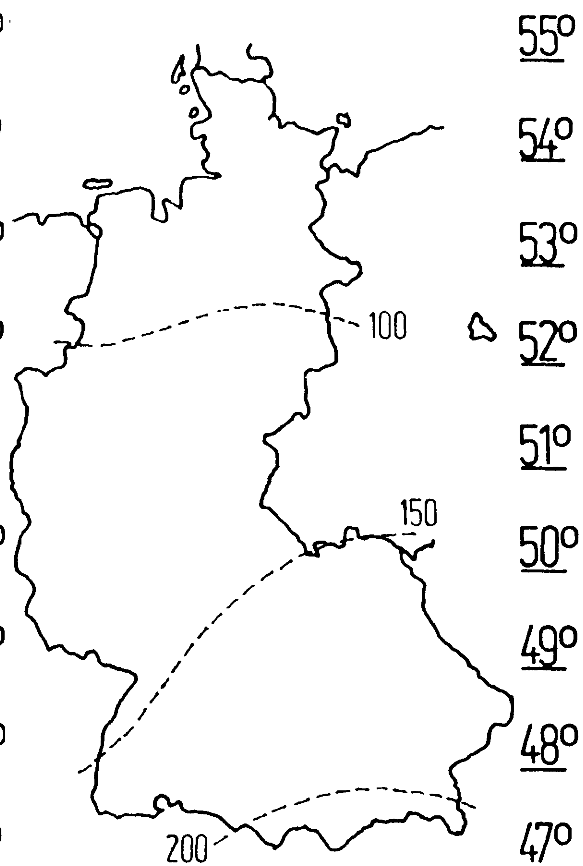


Fig.10
Mean daily amounts of diffuse solar irradiation for Dec.1979 in J/cm^2

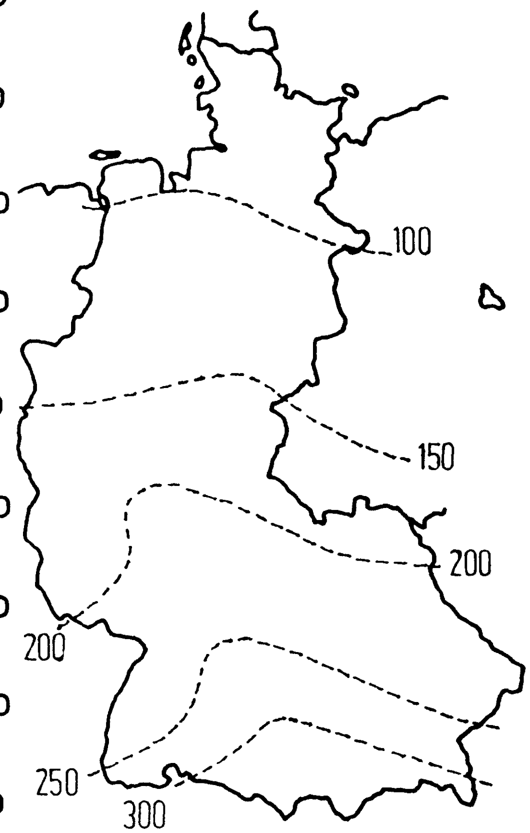


Fig.11
Mean daily amounts of global solar irradiation for Dec.1979 in J/cm^2

tical effects of this area (upwind-effects, lee-side-effects, accumulation-effects).
Due to air-pollution a city like Munich can experience a drop in its radiation level from 415 kJ/cm^{2}year in the outskirts to 395 kJ/cm^{2}year in the city-center.

(4) the Alps

Higher radiation values can be expected in the large open valleys of the inner Alps. They are protected by the northern and southern Alps, are located on a high altitude in dry air and are not affected by air-pollution. But there are large local differences because of shading problems from other mountains, upwind-effects and leeside-effects which can lead to cloud formations.

Annual Swing of Global Radiation in West-Germany

June should be the month with the highest amount of solar insolation. But in the coastal area the maximum is in May/June; in the northern and middle part of Germany in June, whereas in the southern area in July. This is due to the specific meteorological conditions in summer in West-Germany.
The differences between summer and winter are greater in the North than in the South, with an obvious preference of the coastal strip for higher insolation values. Fig. 6 till Fig. 11 show the mean daily irradiation-values (diffuse, direct and global) for June and December 1979 [17]. Radiation contour maps indicate trends over large regions; they should be used with care.
As far as climatical provinces are concerned, similar distinctions can be made for the range of regional air temperatures.

Air Temperatures

(1) the costal region and the lowlands in the northern part of Germany

The influence of the North Sea and the Baltic on climate depends primarily on the thermal behavior of the costal waters. The heat capacity of sea-water is almost double that of soil. Due to the turbulent water flow the heat is absorbed by a rather great mass of water, resulting in a phase lag of the annual temperature extremes of surface water and air. Thus the immediate coastal strip experiences the mean maximum of air temperature as late as in August and the minimum in February. In addition, the retarding influence of water masses levels off the mean annual range of air temperature in the coastal area. This unequal heating and cooling of adjacent land and water surfaces results in an excess of heat at the coast-line in autumn and a deficit of heat in spring in comparison with the interior of the continent. This effect rapidly diminishes towards the inland and towards eastern Europe with increasing distance from the sea. The main axis of increasing continentality runs from the northwest towards southeast with a rise in the mean annual temperature range of 3.5 degrees, from 15.4°C at Jever to 18.9°C at Cottbus.

(2) the Highlands

Orographic effects are quite pronounced in this mountainous terrain, because the intrinsic climatic elements show a well-marked relationship with altitude. The general decrease of air temperature with height shows a seasonal variation:
the vertical lapse rate is greatest in summer; therefore during that time the temperature differences between elevated regions and valleys are most evident. In winter the vertical lapse rate on the average is at a minimum, because due to radiant cooling, valleys, bassins and troughs are often filled with stagnant cold air, the upper limits of which coincides with the top of the ground fog-layer so that the elevated regions are considerably warmer due to bright solar radiation. These ground inversions in low valleys aggravate the problem of air pollution in industrial centers because they prevent the exchange of air in these bassins which also have the disadvantage of low wind speeds. Thus the crests of the highlands are characterized by much smaller diurnal and annual temperature ranges.

(3) the Alpine foreland

Numerous spots of marshy land are embedded in the German Alpine foreland mainly in the valleys of the Danube and its southern tributaries; this marshland is prone to low temperatures not only

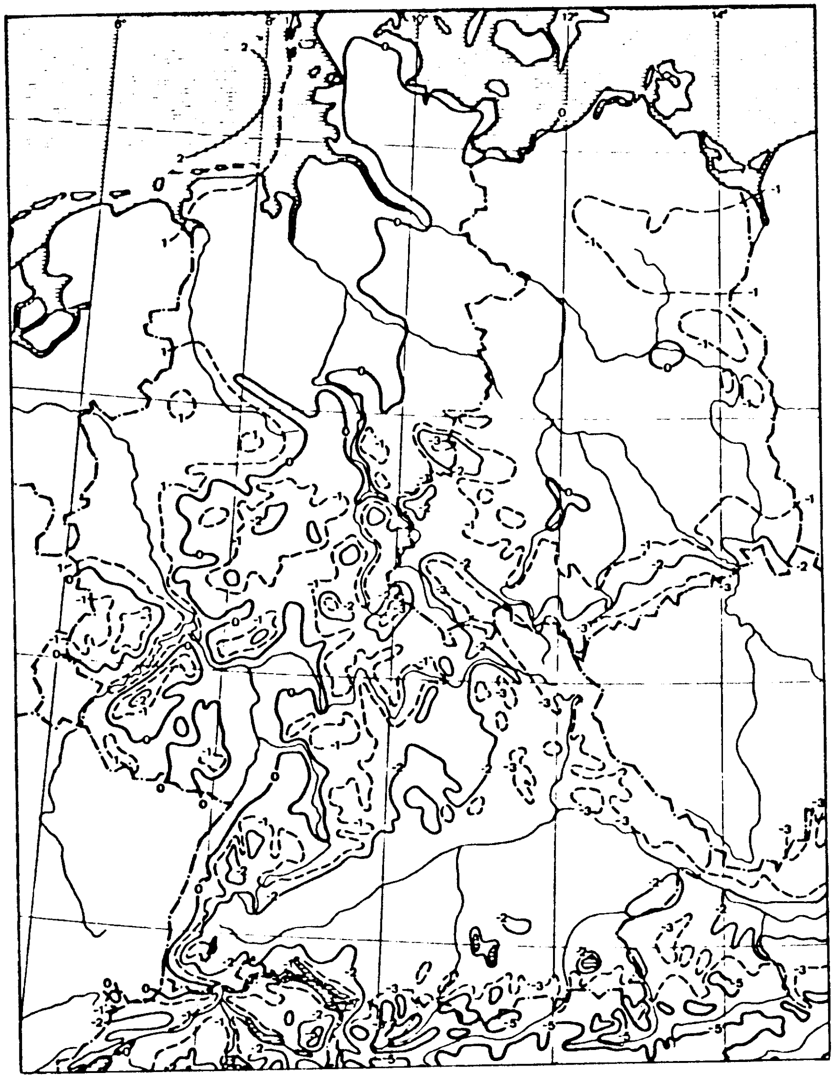


Fig.12 Mean temperature (°C) in January,1931-60

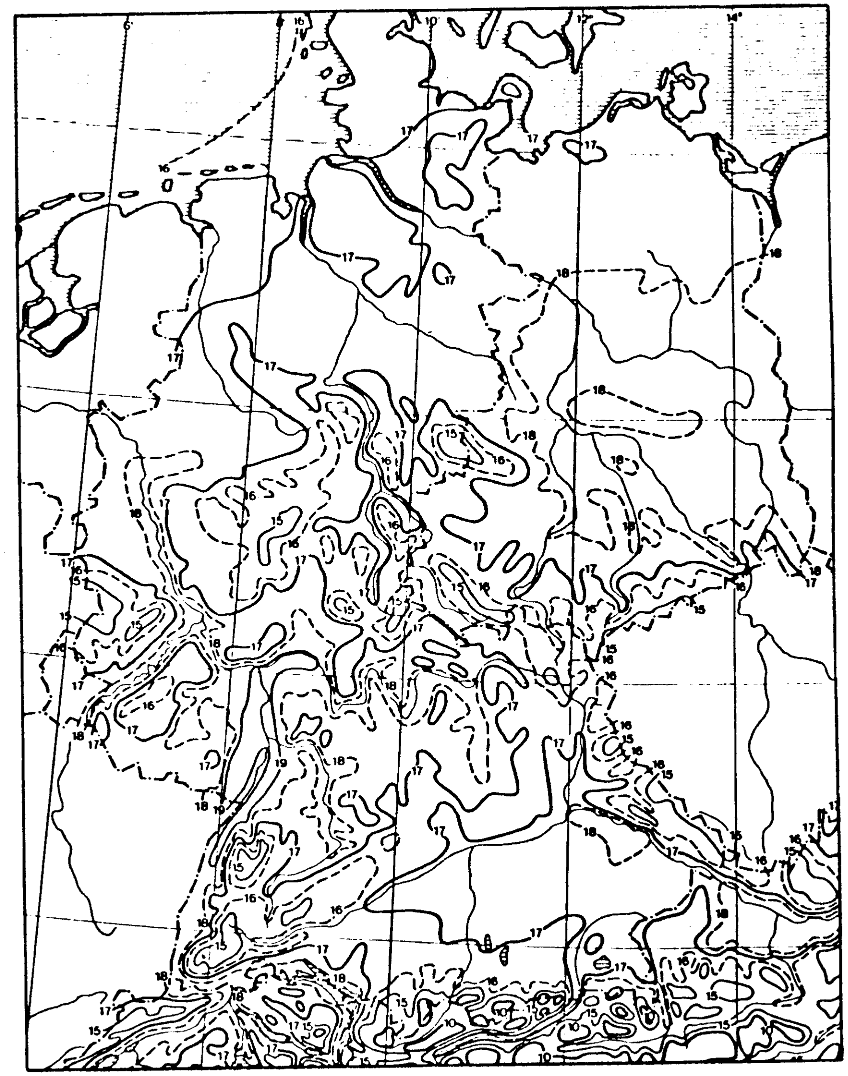


Fig.13 Mean temperature (°C) in July,1931-60

in winter; they also occur in the transitional seasons. The lake effect of the numerous embedded lakes such as Lake Constance is felt mainly in in winter, resultinq in above-average temperatures. In summer the entire area is favored by relatively warm temperatures in spite of the height above sea level (tableland).

(4) the Alps

The formation of layers of cold air in the Alpine valleys in winter also has an impact on the long record means of air temperature; this shows up for instance in the vertical distribution of monthly mean temperatures. In winter the normal lapse rate of 5^{o} - 6^{o}C per 1000m is interrupted in the layer between 700m and 1000m above sealevel, due to the frequent occurance of ground inversions in the valleys. The frequent occurance of inversions also increases the number of fog days. So the valleys trap the cold air, whereas the slope sides between 700 and 1000m above sealevel have the benefit of rather mild temperatures. (Fig.12, Fig.13)

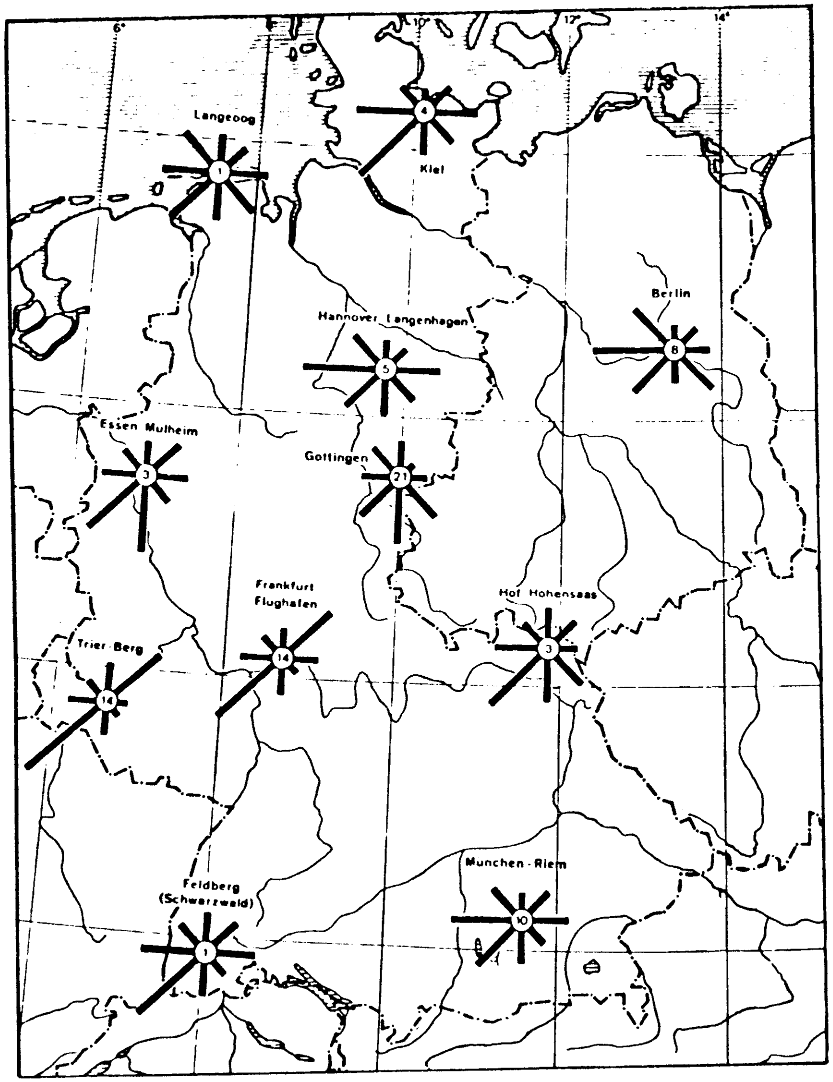


Fig. 14 Annual mean wind distribution (1mm is 2,5%)

Winds

Surface-wind roses of several representative stations are presented in Fig. 14
The values refer to the observational period 1931-60. Figures in the circles are calms. Westerly winds prevail along the North Sea coast. Over the German highlands enhanced surface friction results in the predominance of southwestern winds, which according to the exposure of the observation site may be deflected partly to the west or partly to the south. The Alpine area has a prevailing northwesterly flow. The great variety of local features of wind direction and speed in the highlands and the Alpine valleys is caused by the system of diurnal winds, i.e., the mountain and valley winds. The land -and sea- breeze system is less pronounced.

Basic Weather Data for Climatic Design:

The first step in the process of climatically responsive design is to obtain, and if necessary, to adjust the climatic data.

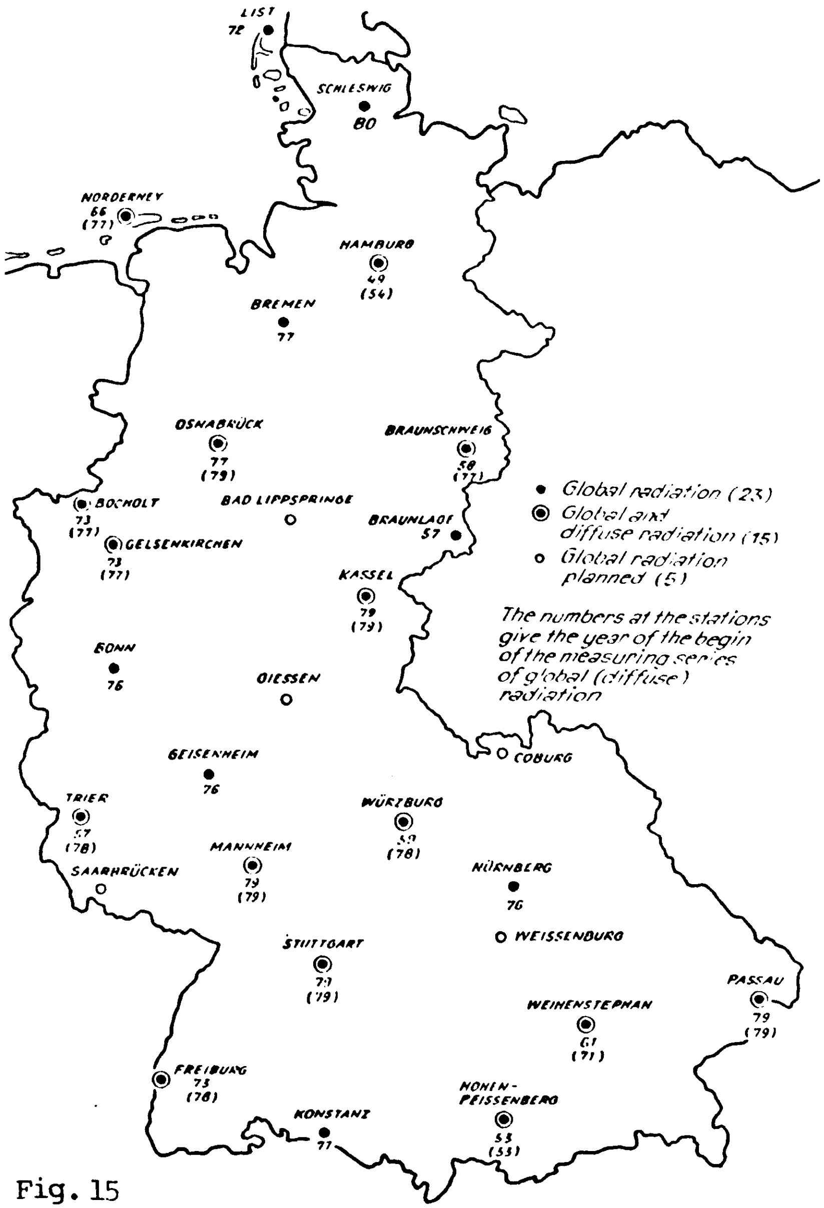


Fig. 15

The design of passively heated buildings requires more climatic information than for conventional ones. The meteorological services in most countries publish fairly detailed statistics for recent decades and these will probably be the best best source of data (see Appendix A).

Radiation Network

The radiation network of the German Weather Service (Deutscher Wetterdienst) measures the global radiation at 23 stations (as of Oct.1. 1980). The diffuse component of the radiation is measured at 15 stations. Not related to the German Weather Service is a station in West Berlin, which measures also global and diffuse radiation. These stations are listed in the following table (Fig.16) with their geographical coordinates (latitude and longitude) and height above sealevel in sequence from North to South. In addition data are listed which indicate for what time period the hourly and daily data of global and diffuse radiation were measured. A map shows the geographical distribution of the stations in West-Germany (Fig.15).[18]

Fig.16 Radiation Network of the German Weather Service

Station	geographical coordinates:			data available as:				checked hourly data on magnetic tape available since	
	latitude	longitude	height above msl	hourly sums since		daily sums since			
				G	D	G	D	G	D
List	55°01'N	08°25'E	33 m	Aug 1972	-	Aug 1972	-	Jan 1976	-
Schleswig	54°32'N	09°33'E	59 m	-	-	-	-	Oct 1980	-
Norderney	53°43'N	07°09'E	29 m	Nov 1966	Nov 1977	Apr 1966	Nov 1977	Nov 1966	Nov 1977
Hamburg-Sa	53°39'N	10°07'E	49 m	-	-	-	-	Jan 1979	Jan 1979
Hamburg-Fu*	53°38'N	10°00'E	14 m	Jul 1949	Jan 1964	Jul 1949	Oct 1954	Jan 1964	Jan 1964
Bremen	53°03'N	08°47'E	24 m	Jan 1977	-	Jan 1977	-	Jan 1977	-
Braunschweig	52°18'N	10°27'E	83 m	Jul 1962	Oct 1977	Jun 1958	Oct 1977	Jan 1966	Oct 1977
Osnabrück	52°15'N	08°03'E	104 m	Mar 1977	-	Mar 1977	-	Mar 1977	Apr 1979
Bocholt	51°50'N	06°32'E	24 m	Feb 1973	Dec 1977	Feb 1973	Dec 1977	Jan 1976	Dec 1977
Braunlage	51°43'N	10°37'E	615 m	Sep 1957	-	Jul 1957		Jan 1966	-
Gelsenkirchen	51°30'N	07°05'E	63 m	Apr 1974	Nov 1977	Oct 1973	Nov 1977	Jan 1976	Nov 1977
Kassel	51°18'N	09°27'E	237 m	-	-	-	-	Feb 1979	Feb 1979
Bonn	50°42'N	07°09'E	65 m	May 1976	-	May 1976	-	May 1976	-
Bad Nauheim**	50°22'N	08°45'E	177 m	-	-	-	-	Jan 1976	-
Geisenheim	49°59'N	07°58'E	113 m	May 1976	-	May 1976	-	May 1976	-
Würzburg	49°48'N	09°54'E	263 m	Jul 1959	Feb 1978	Jul 1959	Feb 1978	Jan 1966	Feb 1978
Trier	49°45'N	06°40'E	277 m	Jan 1964	-	Nov 1957	-	Jan 1966	Jan 1979
Mannheim	49°31'N	08°33'E	105 m	-	-	-	-	Jan 1979	Feb 1979
Nürnberg	49°30'N	11°05'E	312 m	Jun 1976	-	Jun 1976	-	Jun 1976	-
Stuttgart	48°50'N	09°12'E	319 m	-	-	-	-	Oct 1979	Oct 1979
Passau	48°35'N	13°29'E	412 m	-	-	-	-	Mar 1979	Mar 1979
Weihenstephan	48°24'N	11°44'E	469 m	Jan 1961	Dec 1971	Jan 1961	Dec 1971	Jan 1961	Dec 1971
Freiburg	48°00'N	07°51'E	308 m	Jan 1973	Feb 1978	Jan 1973	Feb 1978	Jan 1976	Feb 1978
Hohenpeissenbg.	47°48'N	11°01'E	990 m	Jan 1953	Apr 1953	Jan 1953	Apr 1953	Jan 1966	Jan 1976
Konstanz	47°41'N	09°11'E	450 m	-	-	-	-	-	-
Berlin-Dahlem	52°28'N	13°18'E	51 m	Nov 1965	-	Nov 1965	-	-	-

* closed end of Dec 1979 **closed end of Apr 1977

G: Global radiation D: Diffuse sky radiation

Unfortunately most of these data are only available for a short time-period and are only partly useful. The format, quality and utility of solar climatic information is not nearly as good as one would wish. In general, weather-data should relate to at least 10 years, since shorter periods will exhibit variations from the long term average . [19] Only 8 stations (+ Berlin) meet these requirements for global radiation data and only 2 stations - Hamburg in the north and Hohenpeissenberg in the south - for diffuse radiation (+ Berlin). However a five year period, although less reliable, may still provide useful information if no other data are available. Historically the main intention of collecting weather-data was to provide longterm forecasts for agricultural needs. For that purpose global radiation data were sufficient for a long time. The need for partitioning radiation into its direct and diffuse components arose only with the forced development of solar collectors after the energy crisis of 1973/1974. Since 1977 the German Weather Service installed 13 new stations to measure diffuse sky radiation (= 80% of the now existing network).

Temperatures were measured very accurately for decades (sometimes for centuries). Thus the network of stations for measuring air temperatures is dense enough to provide all relevant informations. Nevertheless these data have to be processed and evaluated in order to fit the needs of climatic responsive design.

CHAPTER 3

CLIMATE OF THE CITY OF WEST - BERLIN

Urban Climate

Climate is defined as "the totality of meteorological phenomena characterizing the average condition of the atmosphere at a given place on the earth's surface".[20]
The question of its influence on cities is, therefore, one of the changes which atmospheric phenomena within cities undergo, and of their causes. Main causes for the development of a special climate within the high density areas of cities are a set of meteorological phenomena described by the term "climatological dome": Increased storage of solar energy in building structures, reduction of wind velocity through higher surface roughness, greater than usual rates of air-pollution increase the ratio of diffuse to direct radiation as well as decrease the total amount of intercepted radiation, local moisture sources are reduced by replacement of forests and fields by concrete and buildings, changes in humidity and water vapor content of the air lead to higher occurrancies of fog formation, air-pollution leads to an increase in rain shower frequency.

Air temperatures were measured at different locations throughout Berlin - see Fig. 17 : they range from 8.3°C in the low density areas like Grunewald to 9.9°C in the center of Berlin. Long term measurements (1964-1978) indicate local temperature differences up to 1.5°C for the area of Berlin.[21]
Enormous amount of dust and smoke produced in a city like Berlin constitute convenient condensation points for water-vapor. The amount of fog will consequently be greater at those times when humidity and the supply of nuclei (particles in the air around which water vapor can condense) are very high. Such is the case both in winter

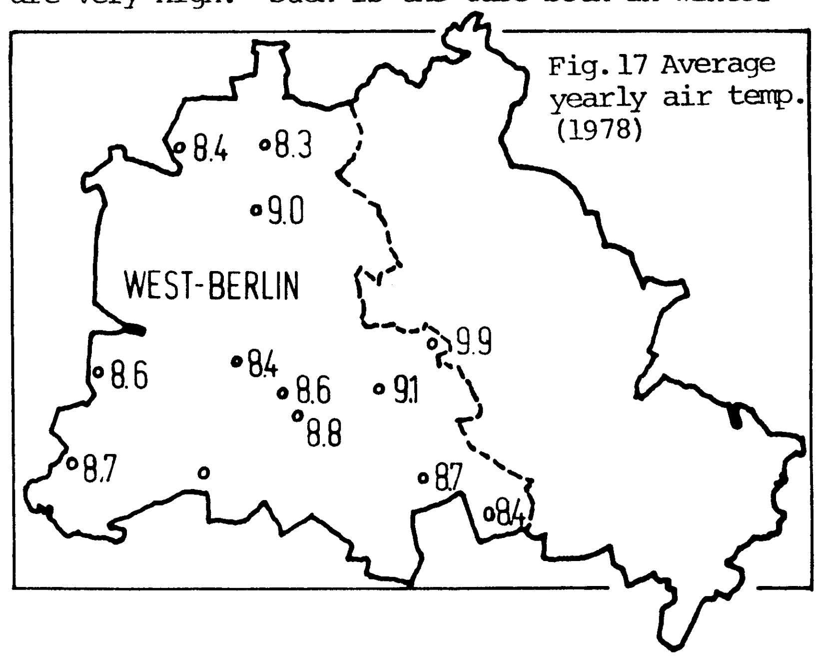


Fig. 17 Average yearly air temp. (1978)

Element	Comparison with Rural Environment
Contaminants:	
condensation nuclei and particles	10 times more
gaseous admixtures	5 to 25 times more
Cloudiness:	
cover	5 to 10 percent more
fog—winter	100 percent more
fog—summer	30 percent more
Precipitation:	
totals	5 to 10 percent more
days with less than 5 mm	10 percent more
snowfall	5 percent more
Relative humidity:	
winter	2 percent less
summer	8 percent less
Radiation:	
global	15 to 20 percent less
ultraviolet—winter	30 percent less
ultraviolet—summer	5 percent less
sunshine duration	5 to 15 percent less
Temperature:	
annual mean	0.5° to 1.0° C more
winter minima (average)	1° to 2° C more
heating degree days	10 percent less
Wind speed:	
annual mean	20 to 30 percent less
extreme gusts	10 to 20 percent less
calms	5 to 20 percent more

Fig. 18 Average changes in climatic elements caused by urbanization

Source: H.E.Landsberg "Urban Climates", 1970

and in the morning. For this very reason the amount of fog is especially large in winter and thus reduces significantly the available solar radiation during the winter months. Average modifications in climatic parameters caused by urbanization are illustrated in Fig. 18

Any kind of weather data, having implications on the design process of inner city buildings should therefore reflect these specific urban climatic conditions. The best source of data will be data from a meteorological station in the city. Two stations in Berlin provided most of the weather data used in this thesis:

The Institute for Meteorology of the Free University of Berlin [22] located in Berlin-Dahlem and the meteorological station at the American airbase Berlin-Tempelhof. [23]

The given data are introduced to the reader by describing their evaluation process. Weather data from the weather service have to be processed in order to be valuable design tools. Outdoor air temperatures and calculation methods to determine their effect on a building's heating load are presented in the following paragraph.

Temperature

Temperatures recorded during any particular month can be characterized by a number of different means[24]:

- "Monthly mean temperature" is the average of the temperatures hourly recorded during a certain month (Necessary for heat-loss-calculations).
- "Mean daily minimum (maximum) temperature" is the average of the minimum (maximum) temperature at the coldest (warmest) time of the day.
- "Mean daily range" is found by subtracting the mean daily minimum from the mean daily maximum.
- "Mean monthly minimum" is the average of the minimum temperatures recorded during the particular month averaged over a number of years (Necessary for vapor-flow calculations).

In designing for thermal comfort these temperatures are the most important, since they indicate the average conditions that will be experienced throughout the month.

The Degree Day Concept

The relationship of the outdoor air temperature to a building's heat load (or cooling load) has led to the concept of the "heating degree day" (or cooling degree day) for predicting the energy consumption of a building. In the case of West-Germany we can focus on heating degree days. Because of fairly moderate temperatures in summer there is no need to consider cooling degree days. Heating degree days are a measure to determine the heat loss (= heat consumption) of a building during a well defined heating period in relation to the local outdoor air temperatures.
Two regulations in Germany lay down the calculation procedure: VDI-Richtlinie 2068 and DIN 4701. They also provide a few weather-data for 134 locations in Germany including 2 locations in West-Berlin. Their weather-data rely on meteorological data for the observation period from 1951 to 1971. Under consideration is only the actual heating period from September 1st to May 31, even if some heating degree days occur during the summer. All days during the heating

period with mean daily outdoor temperatures below 15°C are defined as "heating days." Fig. 19 shows the frequency of occurence for days with a mean daily outdoor temperature below 15°C for Berlin-Dahlem (1954-1974).[25]
Following the given procedure and counting only days below 15°C leads in the case of Berlin-Dahlem to 275 heating days over the range of an entire year. 23 days of the 275 are heating days during the summer months of June, July and August, thus reducing the actual number of heating days to 252 days for the given heating period.

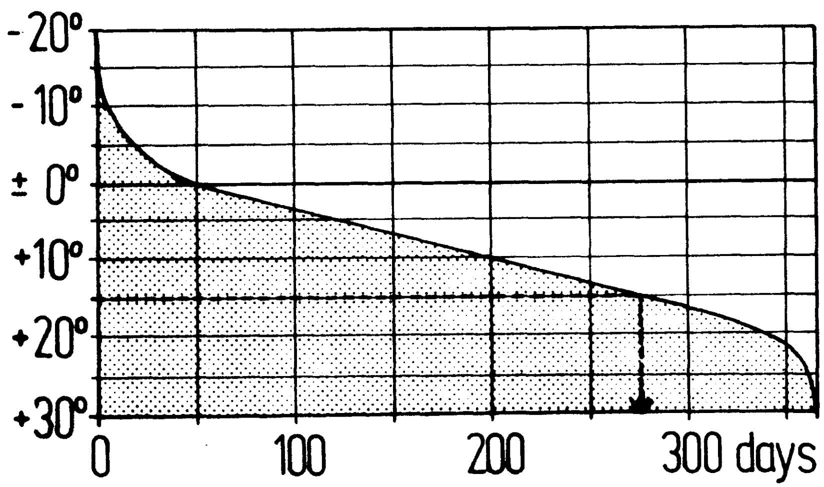


Fig. 19 Mean frequency of occurrence of average daily outdoor air temperatures

This corresponds nicely with the data provided by the VDI-Richtlinie 2067:

	z	t_z	t_i	Δt	z x t=DD
Berlin-Dahlem	252,4	4,9°	20°	15,1°	3809
Berlin-Tempelhof	246,1	5,0°	20°	15,0°	3694

where z = average yearly amount of heating days during the heating period

t_z = mean daily outdoor air temperature for all heating days

t_i = mean indoor air temperature

$\Delta t = t_i - t_z$

DD = degree days for heating period

The mean indoor air temperature is assumed to be 20°C and acts as the degree day base temperature in calculating the degree days.
Recognizing that yearly data are no longer sufficient to generate heat loss calculations, similar monthly values were recently published in HLH 30 (12/1977). For Berlin-Dahlem they are:

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
z	31,0	28,3	31,0	28,4	21,6	8,8	6,0	8,4	20,6	30,5	30,0	31,0
t_z	-0,8	-0,2	3,2	8,1	11,3	12,9	13,6	13,7	12,0	9,4	4,6	0,9
t_i	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0	20,0
Δt	20,8	20,2	16,8	11,9	8,7	7,1	6,4	6,3	8,0	10,6	15,4	19,1
DD	645	572	520	338	188	63	38	54	166	324	463	593

Total yearly heating degree days : 3964

Degree days during heating period:

$$3964-(63+38+54) = 3809$$

By assuming that t_i equals 20°C this method overestimates the amount of heating degree days necessary to keep a house in a comfortable temperature range during the heating period. Would this method still be valid if a $t_i < 20°C$ is chosen? Lowering t_i is useful if the effects of internal gains, different thermostat settings during day and night as well as better insulation are taken in account. This requires calculating the degree day base temperature for each different building according to its conduction and infiltration losses as well as its internal gains, instead of leaving it constantly at 20°C. The "adjusted" degree day base temperature is then called "balance point temperature."

Balance Point Temperature

A building's balance point temperature defines the ambient air temperature at which the building's heating system starts to supply energy to the space in order to keep it at the temperature of the thermostat setting.[26] Or: the balance point temperature is the outdoor air temperature above which no auxiliary heating is required for the building. Internal gains fill the temperature gap between the temperature of the thermostat setting and the balance point temperature until the ambient air temperature reaches the balance point.

The balance point temperature t_{bp} equals

$$t_{bp} = \text{average daily thermostat setting} - \frac{\text{internal gains/day}}{\text{building heat losses/day}}$$

Example:

$$t_{bp} = 18^{\circ}C - \frac{24 KWh/day}{8\ KWh/day\ ^{\circ}C} = 18^{\circ}C - 3^{\circ}C = 15^{\circ}C$$

Increased insulation or lower infiltration rates will lower the building's heat losses and therefore lower the balance point temperature too.

Example:

$$t_{bp} = 18^{\circ}C - \frac{24\ KWh/day}{6\ KWh/day\ ^{\circ}C} = 18^{\circ}C - 4^{\circ}C = 14^{\circ}C$$

By replacing the degree day base temperature with the "adjusted" balance point temperature we also can adjust the necessary heating degree days. Heating degree days for a certain month (or a year) are usually obtained by multiplying the difference between the balance point temperature and the mean monthly (yearly) outdoor air temperature by the number of days per month (year):

$$DD = (t_{bp} - t_z) \times N$$

where DD = degree days per month (year)

t_{bp} = balance point temperature

t_z = mean monthly (yearly) outdoor air temperature

N = number of days during the calculation period

Example:

Assuming a balance point temperature of $16^{\circ}C$ and a monthly mean outdoor temperature of $8,1^{\circ}C$ for April (28,4 heating days), this month has 224,4 heating degree days:

$(16^{\circ}C - 8,1^{\circ}C) \times 28,4 = 224,4$ DD

Fig. 20 shows the influence of different balance point temperatures on the length of the heating period (= number of heating degree days). The lower the balance point temperature, the smaller the heating period (= less heating degree days). The mean outdoor air temperature is $8.8^{\circ}C$. This value reduces to roughly $5.9^{\circ}C$ if one considers only the 8½ month heating period below a t_{bp} of $15^{\circ}C$, and it changes to 3.7° for the 6½ month heating period below a t_{bp} of $10^{\circ}C$.

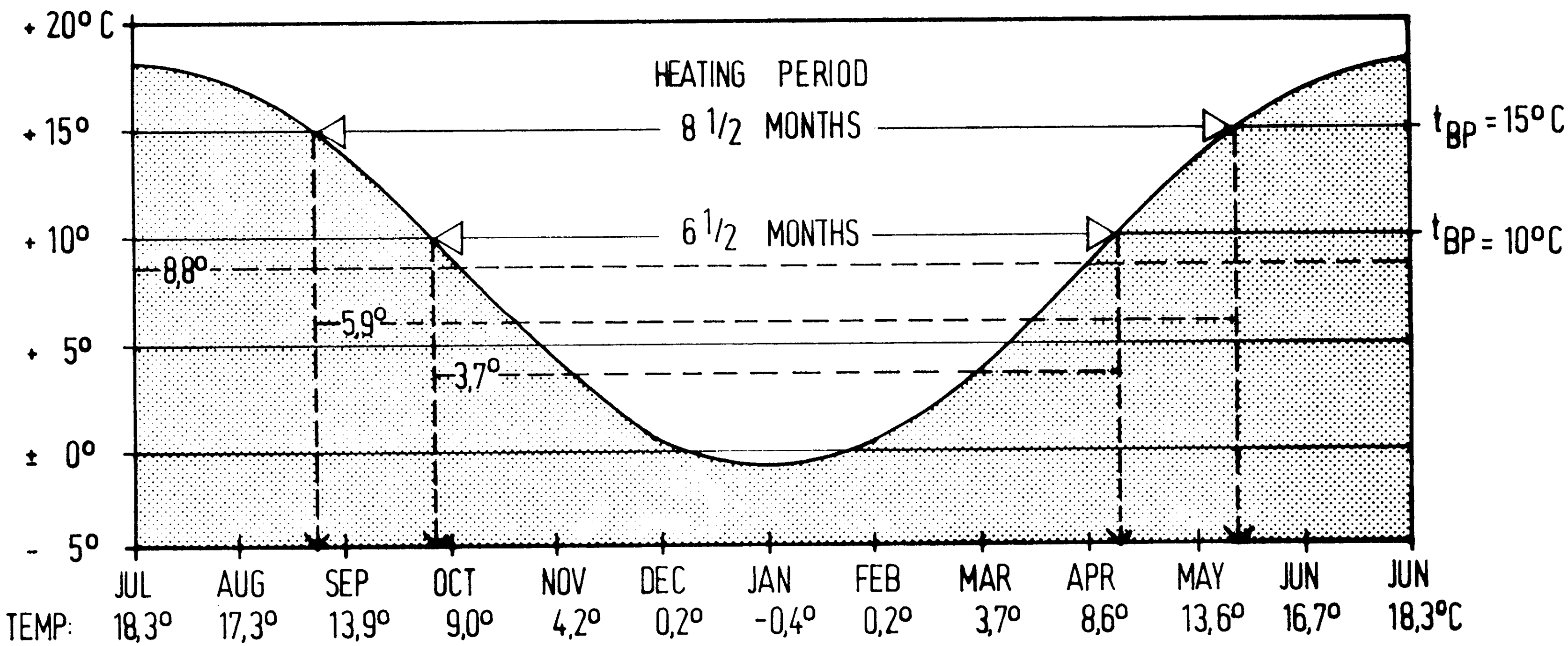


FIG. 20 YEARLY DISTRIBUTION OF MONTHLY MEAN OUTDOOR AIR TEMPERATURE FOR BERLIN-DAHLEM (1909 - 1969)

SOURCE: BEILAGE ZUR BERLINER WETTERKARTE, 20.3.1979

As a result of this reconsideration, the values of the mean monthly outdoor air temperatures also have to be changed as part of an adjusted calculation method for heating degree days. If these values were kept constant, they wouldn't reflect the changing range of affected temperatures which are lower than the balance point temperature. To demonstrate this objective, the mean hourly outdoor air temperature profile for April is plotted in Fig. 21 (The monthly profiles of 8 other months with heating days are shown on the following page , by using the BIN-data of Berlin-Tempelhof [23])

Each different balance point temperature generates a different number of heating degree days according to the different sizes of cut-out areas under the distribution curve. To compute the heating degree days for each month a method (BIN-data preparation program by Tim Johnson and Chris Benton) is used which converts BIN-data for a monthly (or yearly) time period into a summary of hourly occurrencies for each temperature bracket and the degree days resulting from a balance point temperature at each temperature bracket, see Fig. 22

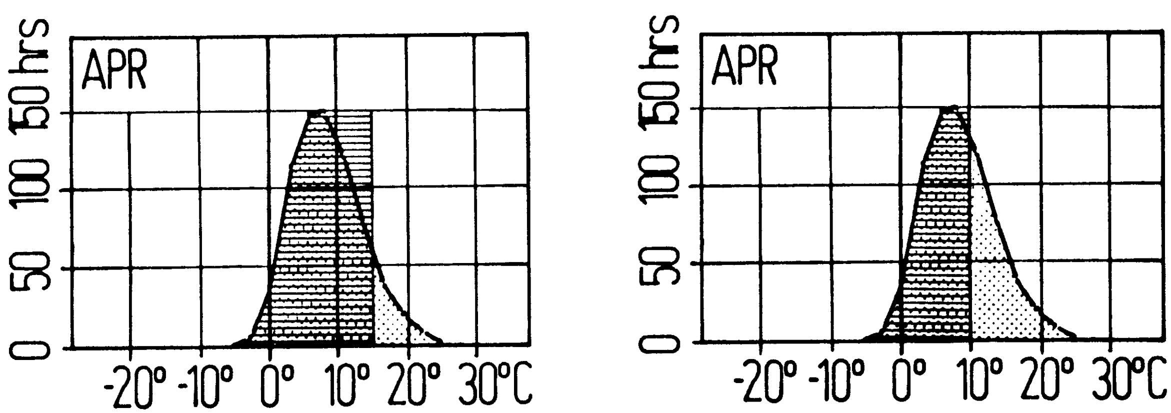


Fig. 21

$t_{bp} = 15^{o}C$
heating degree days: 190

$t_{bp} = 10^{o}C$
heating degree days: 72

MEAN FREQUENCY OF OCCURRENCE OF DRY BULB TEMP. FOR BERLIN-TEMPELHOF

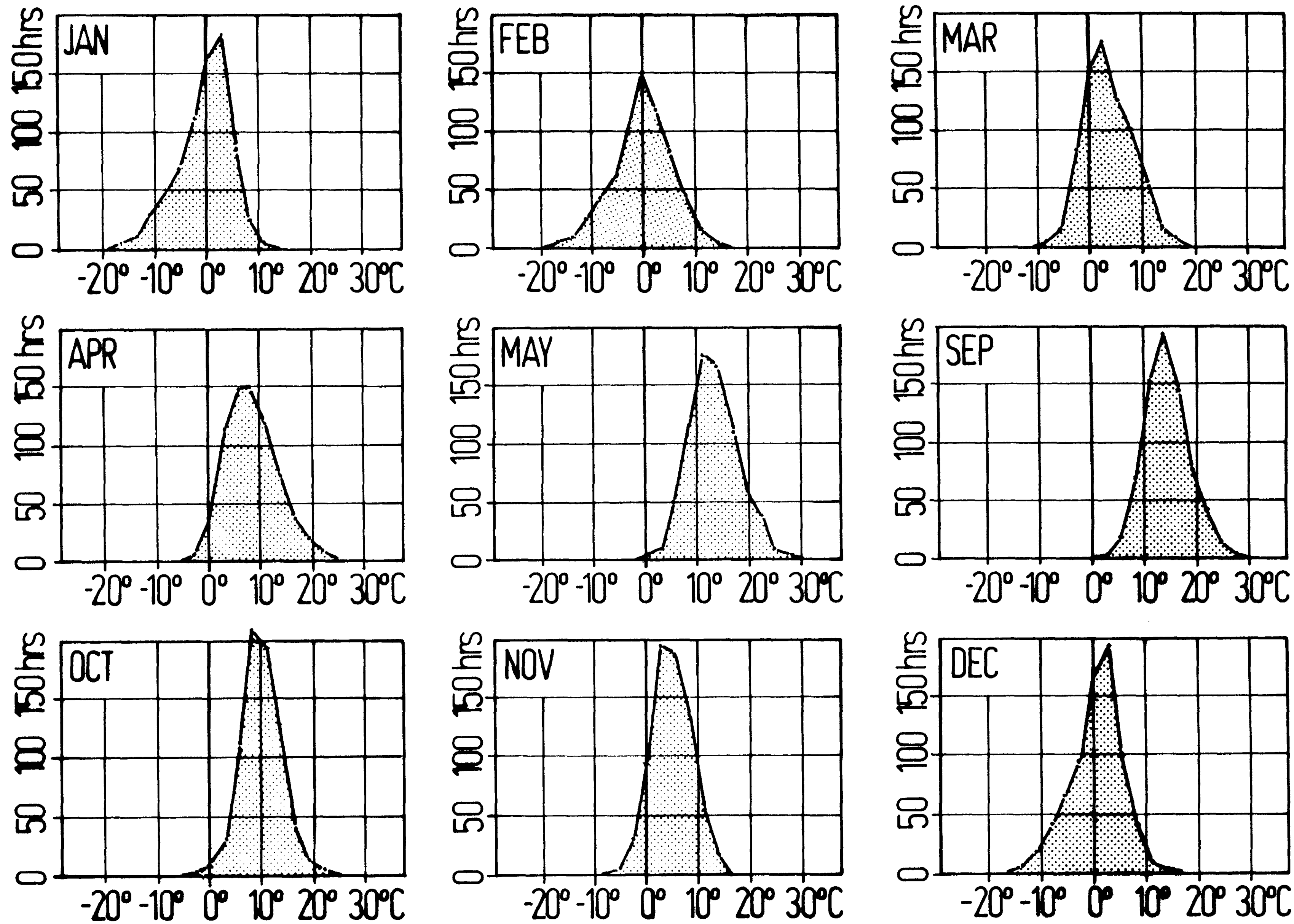


Fig. 22

t_{bp} in: °F	°C	Degree days (°C) for Berlin-Tempelhof (BIN-data) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
69,9	21	652	577	518	360	232				184	302	469	568	3 862
68,0	20	621	549	488	331	203				157	272	439	538	3 598
66,2	19	590	521	457	302	176				131	242	409	509	3 337
64,4	18	559	493	426	273	149				106	212	379	482	3 079
62,6	17	528	465	395	245	123				82	182	349	455	2 824
60,8	16	515	437	364	217	100				62	154	319	427	2 595
59,0	15	466	409	334	190	78				44	126	290	400	2 337
57,2	14	435	381	303	163	56				26	98	260	373	2 095
55,4	13	404	353	274	139	40				15	75	230	346	1 876
53,6	12	373	325	244	115	25				4	52	198	319	1 655
51,8	11	342	297	215	91	11				-	30	172	292	1 450
50,0	10	312	270	187	72	-				-	16	145	265	1 267
48,2	9	281	243	160	53	-				-	1	118	238	1 094
46,4	8	250	216	134	36	-				-	-	92	212	940
44,6	7	221	191	110	24	-				-	-	71	187	804

The computed degree days of each month (year) follow the line of a cubic curve.

Fig.23

t_{bp} in: °F	°C	Degree days (°C) for Berlin-Dahlem (VDI-Richtlinie 2067) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual
69,9	21	676	600	551	366	210				187	355	493	624	4 062
68,0	20	645	572	520	338	188				166	324	463	593	3 809
66,2	19	614	543	489	310	166				144	293	433	562	3 554
64,4	18	583	515	458	281	145				124	262	403	531	3 302
62,6	17	552	487	427	253	123				103	232	373	500	3 050
60,8	16	521	458	396	224	102				82	201	343	469	2 796
59,0	15	490	430	365	196	80				62	171	313	438	2 545
57,2	14	459	402	334	168	58				41	140	283	407	2 292
55,4	13	428	374	303	139	37				21	110	253	376	2 041
53,6	12	397	345	272	111	15				-	79	223	345	1 787
51,8	11	366	317	241	82	-				-	49	193	314	1 562
50,0	10	335	289	210	54	-				-	18	163	283	1 352
48,2	9	304	260	179	26	-				-	-	133	252	1 154
46,4	8	273	232	148	-	-				-	-	103	221	977
44,6	7	242	204	117	-	-				-	-	73	190	826

Using the data provided by VDI-Richtlinie 2067, one can compute a similar list of degree days for each month (year), see Fig.23 .

The calculation follows the simple equation

$$DD = z \times t_{bp} - t_z \times z$$

where z = number of heating days per month (year)

t_{bp} = balance point temperature

t_z = mean monthly (yearly) outdoor air temperature.

Conclusion:

The plotted annual distribution curves of heating degree days, calculated with BIN-data on the one hand and with VDI-Richtlinie 2067 on the other, show a close congruence in the balance point temperature range from 12° to 18°C, see Fig.24,25. If the balance point temperature drops below 12°C, the BIN-data method proves to be more precise.

Fig.24 Mean frequency of occurrence of dry bulb temperature per year for Berlin-Tempelhof

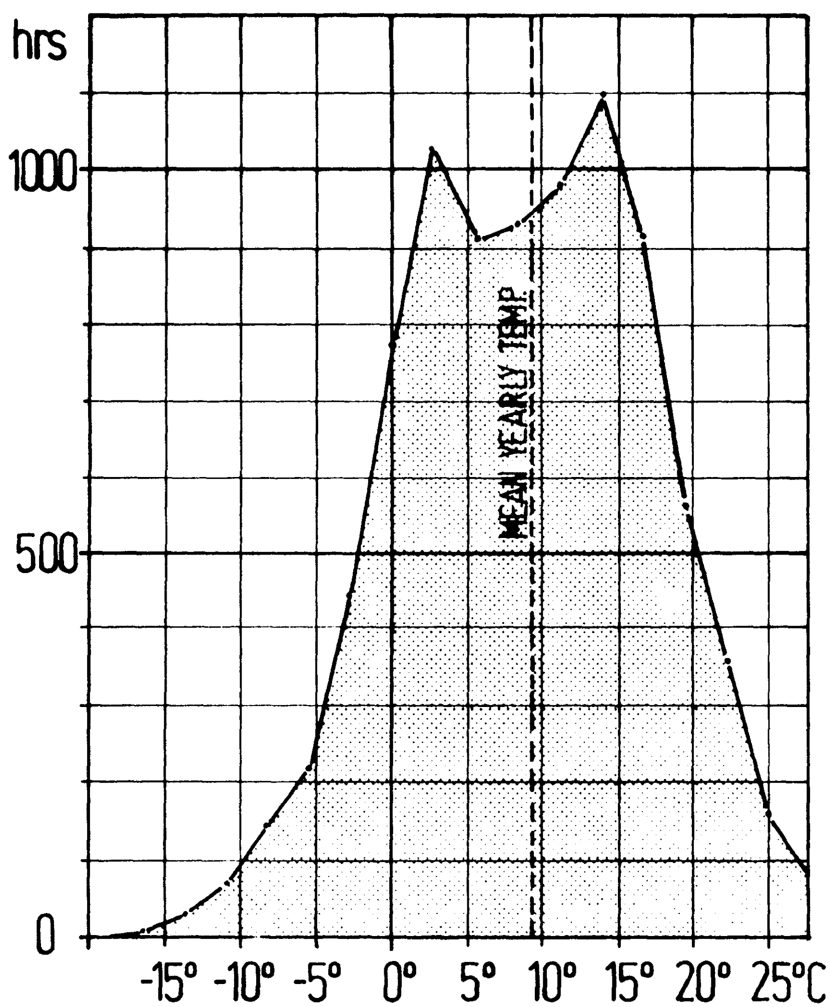
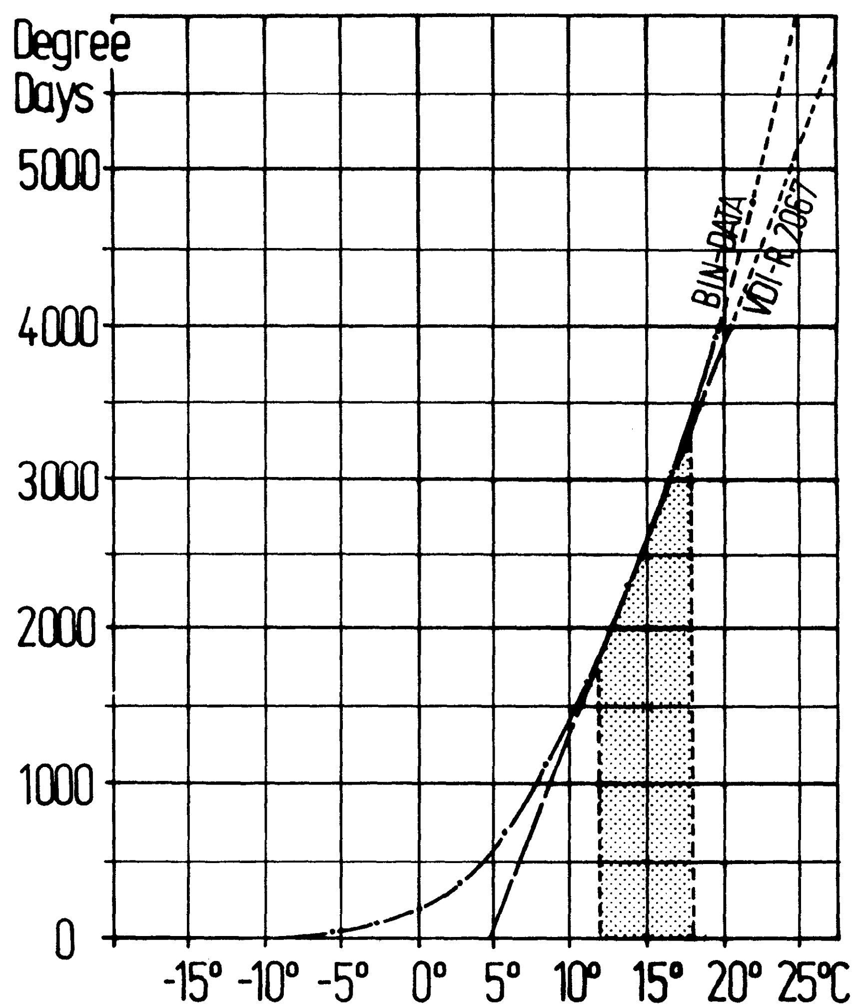


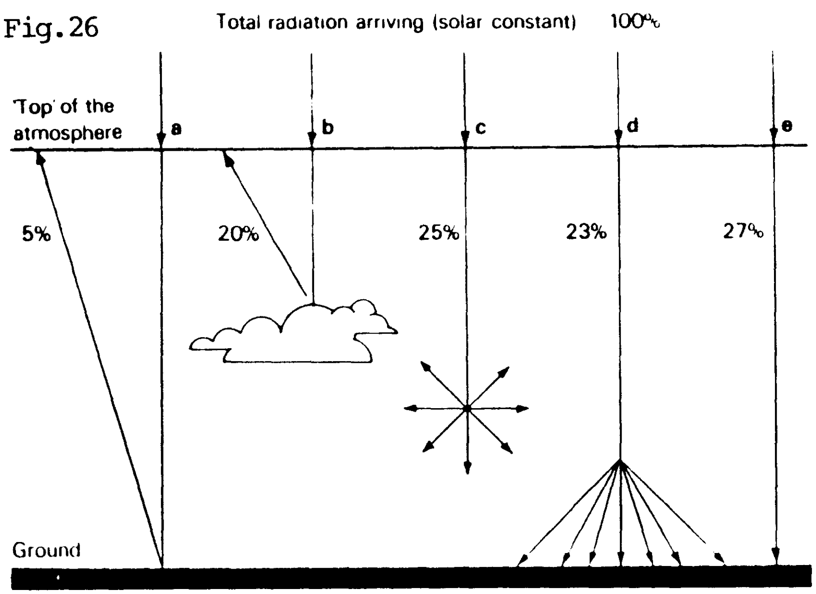
Fig.25 Distribution of degree days in relation to balance point temperature for Berlin-Tempelhof



Components of Solar Radiation

On entering the earth's atmosphere solar radiation splits into three components (Fig. 26):
One part is absorbed by water vapor and ozone.
The second part is scattered by air molecules, water vapor molecules and dust particles. This part, the direction of which is changed by reflection and scattering is called "diffuse radiation." On a very clear day, the diffuse component amounts to 10 or 20% of the total solar radiation; on an overcast day, it can be 100% of the - relatively small - total. The third part, which reaches the earth unaltered is called "direct radiation." In other words: direct radiation is that solar radiation which is received from the sun without change of direction. The total solar energy reaching the earth's surface is the sum of the diffuse and direct radiation, called "global radiation."
Owing to scattering and absorption, the solar radiation reaching the earth is less than that available outside the earth atmosphere. The reduction in intensity depends on atmospheric conditions (amount of dust particles, water vapor, ozone content, atmospheric pressure, etc.) and solar altitude.

Fig. 26



		%
a =	reflected from the ground	5
b =	reflected from the clouds	20
c =	absorbed in the atmosphere	25
d =	diffuse, on the ground	23
e =	direct, on the ground	27
	Total on the ground	50

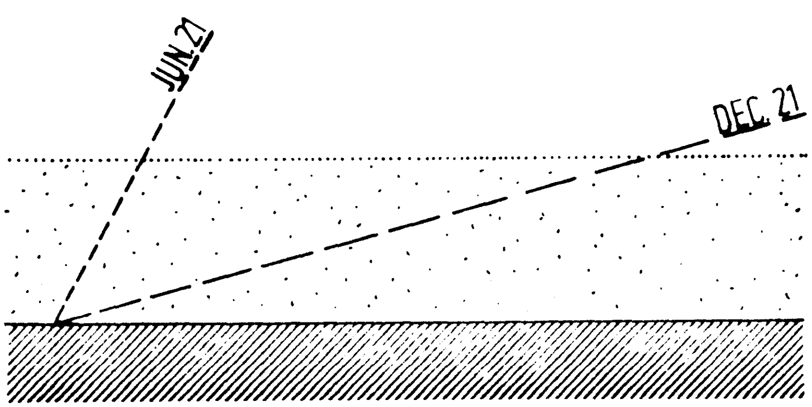
Solar time	January		February		March		April		May		June	
	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm
4•• / 20••	-	-	-	-	-	-	-	-	-	-	2.1	127.3
5•• / 19••	-	-	-	-	-	-	0.3	108.9	7.1	113.8	9.9	115.9
6•• / 18••	-	-	-	-	-	-	9.2	97.1	15.7	102.5	18.4	104.8
7•• / 17••	-	-	0.3	71.6	9.1	78.0	18.3	85.2	24.8	91.0	27.4	93.5
8•• / 16••	0.8	54.5	8.6	59.3	17.7	65.4	27.2	72.6	33.9	78.6	36.5	81.3
9•• / 15••	7.6	42.1	15.9	46.2	25.5	51.6	35.5	58.3	42.5	64.3	45.3	67.2
10•• / 14••	12.9	28.8	21.7	31.9	31.8	36.0	42.5	41.6	50.1	47.0	53.1	49.8
11•• / 13••	16.3	14.7	25.4	16.3	36.0	18.6	47.4	22.0	55.5	25.4	58.8	27.7
12••	17.5	0.0	26.7	0.0	37.5	0.0	49.1	0.0	57.5	0.0	61.0	0.0

Solar time	July		August		September		October		November		December	
	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm	Alt	Azm
4•• / 20••												
5•• / 19••	7.6	114.2	0.9	109.3	-	-	-	-	-	-	-	-
6•• / 18••	16.2	102.9	9.7	97.6	-	-	-	-	-	-	-	-
7•• / 17••	25.6	91.4	18.8	85.7	9.1	78.0	0.6	71.8	-	-	-	-
8•• / 16••	34.3	79.0	27.8	73.0	17.7	65.4	8.9	59.5	1.0	54.6	-	-
9•• / 15••	43.0	64.8	36.1	58.8	25.5	51.6	16.2	46.4	7.8	42.2	4.5	40.6
10•• / 14••	50.6	47.5	43.2	42.1	31.8	36.0	22.0	32.0	13.1	28.9	9.7	27.7
11•• / 13••	56.0	25.7	48.0	22.2	36.0	18.7	25.7	16.4	16.5	14.7	12.9	14.1
12••	58.1	0.0	49.8	0.0	37.5	0.0	27.0	0.0	17.7	0.0	14.0	0.0

Fig. 27 Solar positions for 52.5° North Latitude

Solar Position

The solar position (Fig.27) determines the length of atmosphere which the sun's beam has to pass before reaching the earth's surface. If the altitude of the sun is small (Noon Dec. 21, Berlin $52^{\circ}30'$NL: 14° above the horizon), the length traversed by the beam is long. On the other hand, if the sun is at its highest point (Noon June 21., Berlin $52^{\circ}30'$NL: 61°) the path length of the sun's beam through the atmosphere is shorter therefore supplying more solar energy in summer than in winter. Similar effects are true for the diurnal path of the sun.



The Meteorological Institute of the Free University of Berlin measured radiation data (global and diffuse) in Berlin-Dahlem since Nov. 1965.[22] The mean monthly values of daily irradiation on a horizontal surface are given in Fig. 28.

Fig. 28 Mean monthly values of daily irradiation for Berlin-Dahlem (Wh/m^2) 1965-1977

month	Jan	Feb	Mar	Apr	May	Jun
global	595	1130	2373	3444	4669	5374
diffuse	469	794	1420	1978	2464	2769
direct	126	336	953	1466	2205	2605

month	Jul	Aug	Sep	Oct	Nov	Dec
global	5163	4471	2942	1532	737	447
diffuse	2704	2229	1598	987	542	386
direct	2459	2242	1344	545	195	61

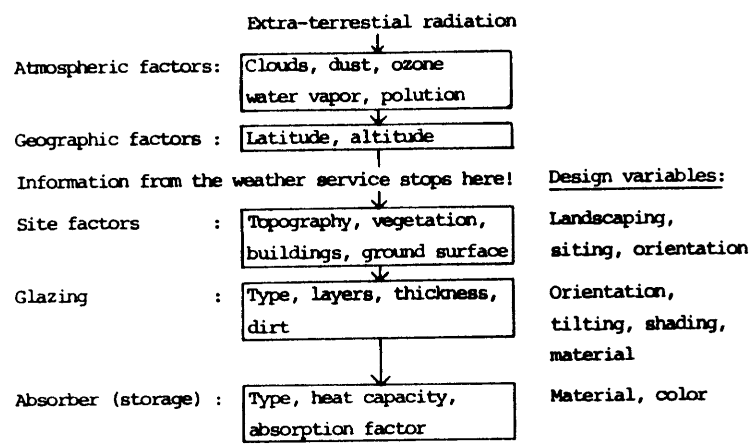
In his dissertation Dipl.-Ing. Axel Jahn generated a Test-Reference-Year (TRY) for Berlin using an evaluated set of weather data provided by the Meteorological Institute of the Free University of Berlin.[27]
His values for average daily irradiation only differ slightly, see Fig.29 :

Fig. 29 Test-Reference-Year: monthly values of irradiation for Berlin-Dahlem (Wh/m^2) 1963-1975

month	Jan	Feb	Mar	Apr	May	Jun
global	602	1146	2361	3349	4692	5317
diffuse	474	789	1412	1968	2503	2741
direct	128	357	949	1381	2189	2576

month	Jul	Aug	Sep	Oct	Nov	Dec
global	5158	4464	3063	1609	733	439
diffuse	2737	2233	1619	903	541	356
direct	2421	2231	1444	706	212	83

Knowing the amount of solar irradiation intercepted by a horizontal surface doesn't tell how much of it will get inside a building. The graph below illustrates the factors that intervene between the sun and the inside of a building:



Solar Geometry

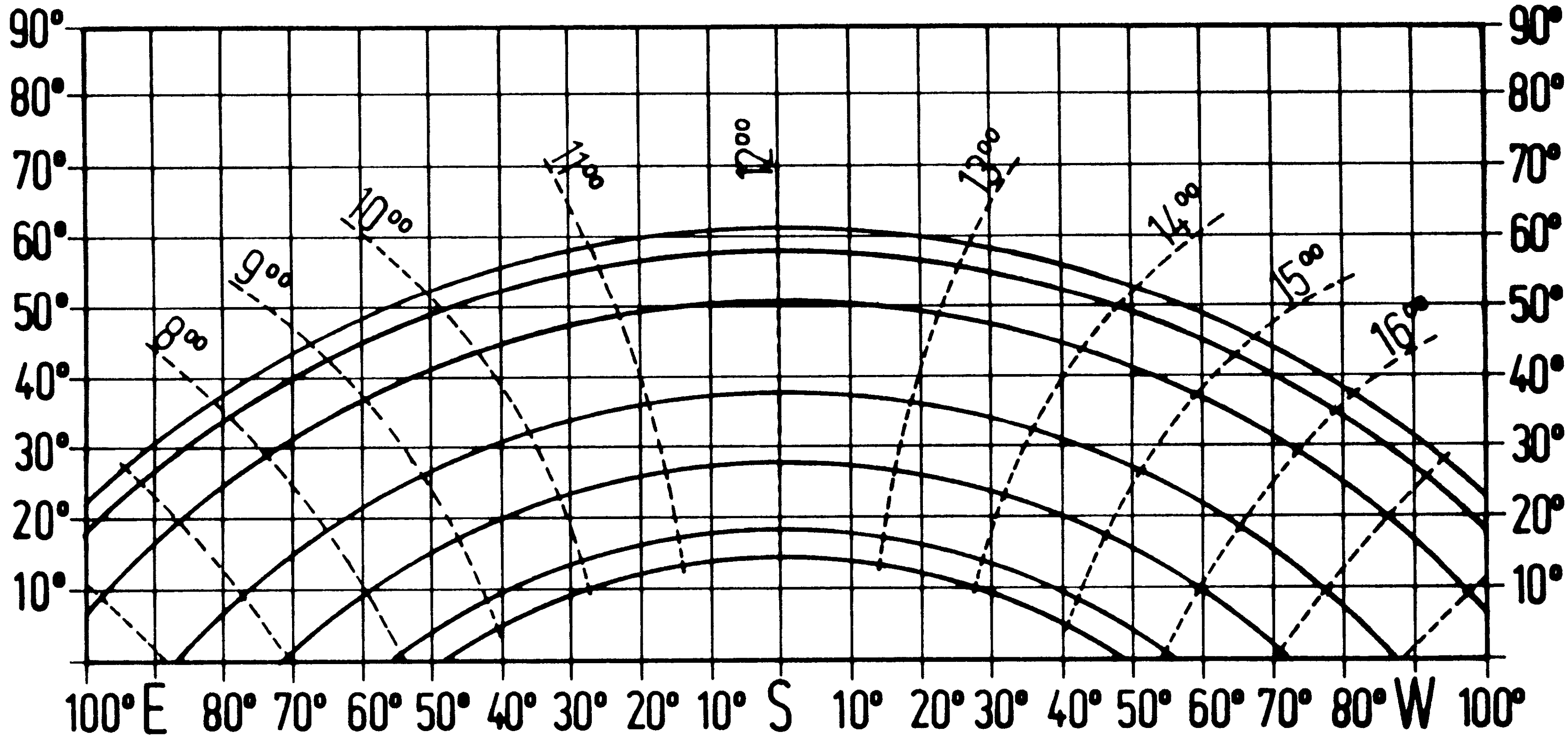
The ability to predict the location of the sun in the sky is critical to passive solar design, since it is the influence of the sun on the building that is the heart of the entire concept. Especially important is the estimation of solar gains to be obtained through glazings as influenced by factors such as orientation, tilt and shading, either by building appurtenances such as overhangs or side walls, or by elements such as trees or other buildings. Equally significant is to determine shading devices to minimize solar gains in summer.

There are various tools available which aid in predicting the location of the sun in the sky and its influence on the building. Some are graphical (sun-charts), some are mathematical and some utilize a scale model of the building in conjunction with a light source to simulate the actual situation. For the purpose of this thesis the use of a sun-chart is sufficient. [28,29,30,31]

Sun Chart

A sun chart is a pictorial representation showing the position of the sun in the sky vault at various times of the year. A pictorial representation, being necessarily two-dimensional cannot satisfactorily represent the three-dimensional sky vault. The curved surface of the hemisphere of sky cannot be spread out on a flat surface like paper without a great deal of distortion, such as occurs in the projections of the globe in geographical maps. This difficulty is obviated by using methods of projecting in which the hemispherical sky vault is projected on a flat sheet.
A method of projection (Mercator-projection) is chosen which provides an easy-to-understand and convenient way to predict the sun's movement across the sky. The sun chart (see next page) is a vertical projection of the sun's path as seen from the earth at 52°North Latitude, close enough to Berlin's 52°30'NL. The equidistant rectangular grid on the chart represents the vertical (altitude) and horizontal (azimuth =

SUN CHART FOR 52° NORTH LATITUDE



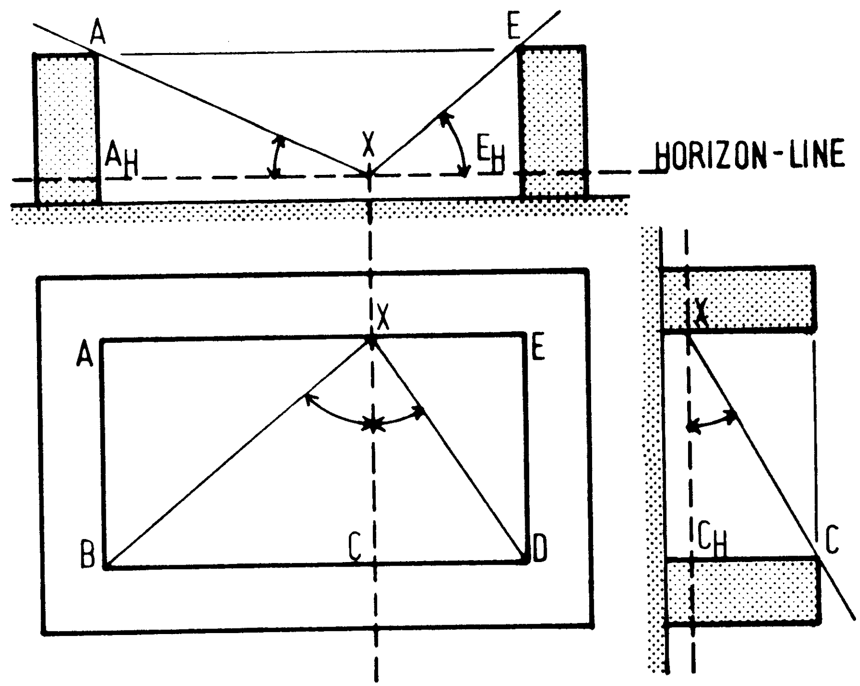
bearing angle) angles of the southern half of the skydome. The 360° degrees of the entire sky vault are reduced to the necessary 200° degrees showing the actual yearly path of the sun for 52° North Latitude.

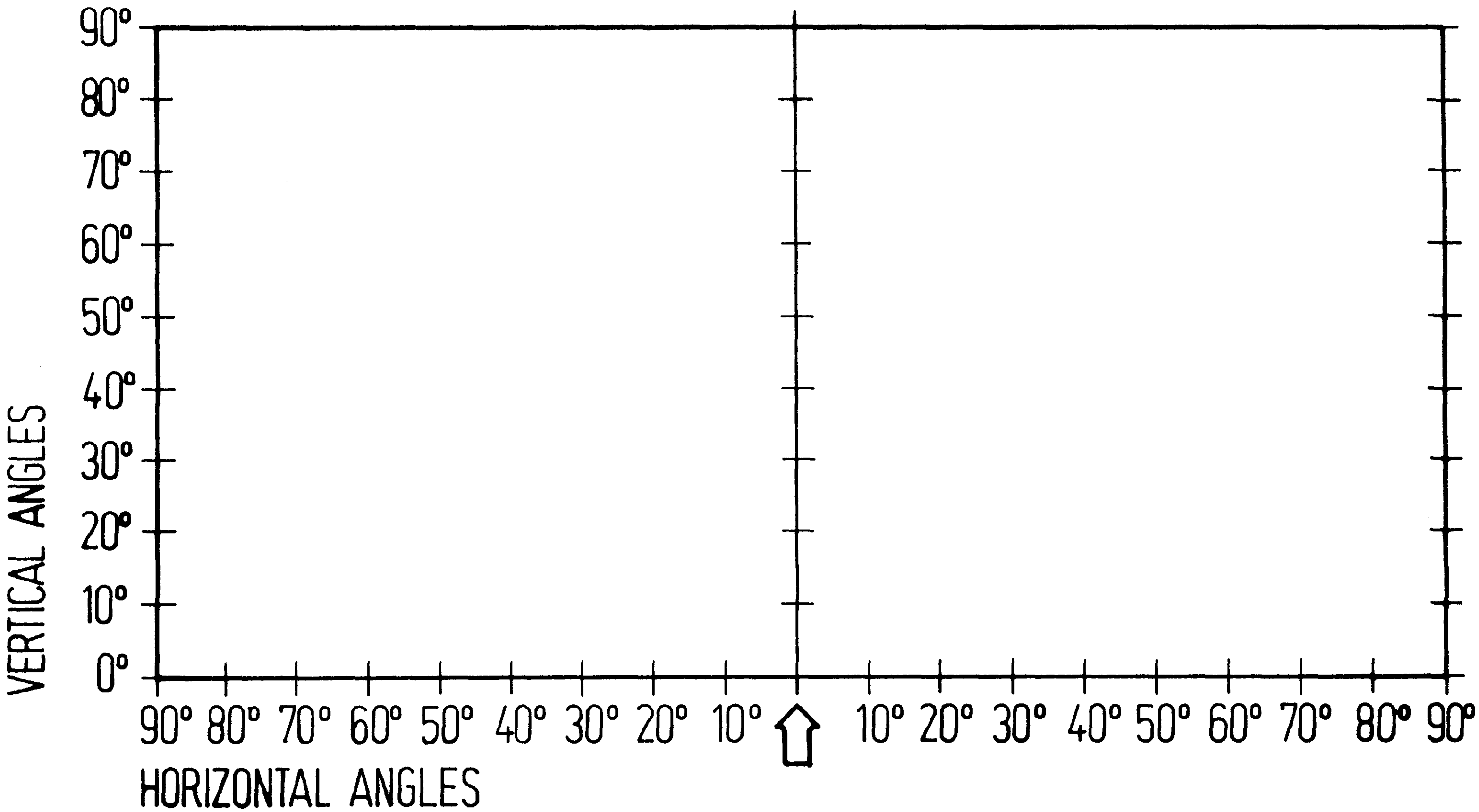
Shading Mask

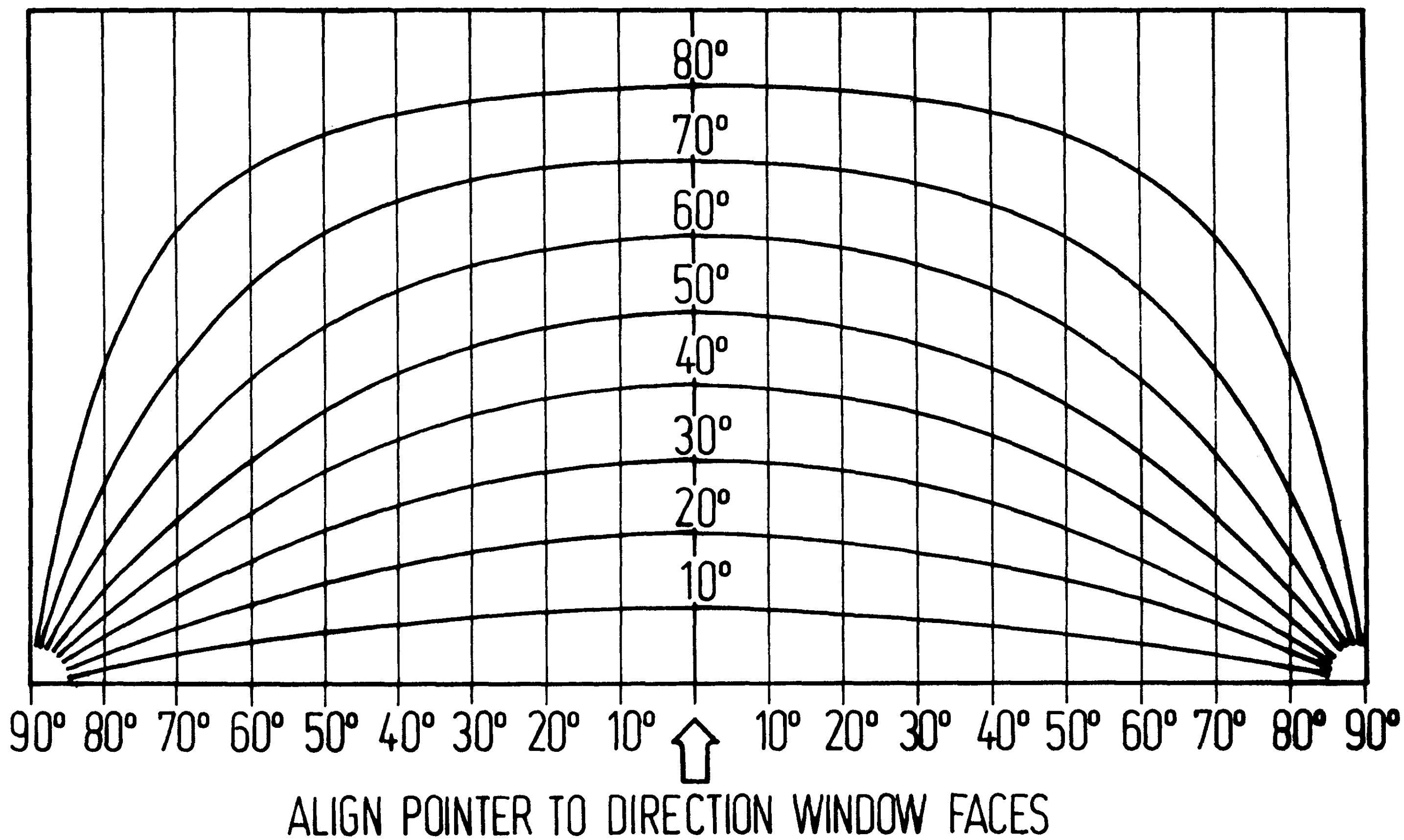
In order to determine the degree of feasibility for solar heating of a certain southfacing building one needs precise information about the solar radiation intercepted by the surfaces (walls or windows) of this particular building. Surrounding obstructions like other buildings or trees might block parts of the direct and diffuse sunlight from reaching the surface.

For any given surface, therefore, a "shading mask" can be constructed. Since the mask is a geometric description of the shading characteristic of a particular obstruction, it is not dependent on latitude, orientation or time of the year.

In the construction of shading masks, the observation or reference point (point X) forms the center of the diagram. The limits of the obstructions vertically and horizontally are plotted on a plan, equal to the size of the sun chart. The vertical limiting angles of obstruction determine the vertical shadow angles: the horizontal limiting angles the the horizontal shadow angles. The construction of a shadow mask for external obstructions (a courtyard situation) has been illustrated below with a suitable example.




90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
VERTICAL ANGLES
90° 80° 70° 60° 50° 40° 30° 20° 10° 10° 20° 30° 40° 50° 60° 70° 80° 90°
HORIZONTAL ANGLES


80°
70°
60°
50°
40°
30°
20°
10°
90° 80° 70° 60° 50° 40° 30° 20° 10° 10° 20° 30° 40° 50° 60° 70° 80° 90°
ALIGN POINTER TO DIRECTION WINDOW FACES

Construction of a Shadow Mask

Step one: Establish the corresponding horizontal shadow angles of the court wall corners opposite to point X (Fig.):

Horizontal angles $\sphericalangle BXC = \tan \frac{\overline{BC}}{\overline{XC}}$

$$\sphericalangle DXC = \tan \frac{\overline{CD}}{\overline{XD}}$$

Step two: Mark both angles on the shading mask (use a transparent sheet): angle $\sphericalangle$ BXC on the right side of the center-axis and angle $\sphericalangle$ DXC on the left side (Fig. 30):

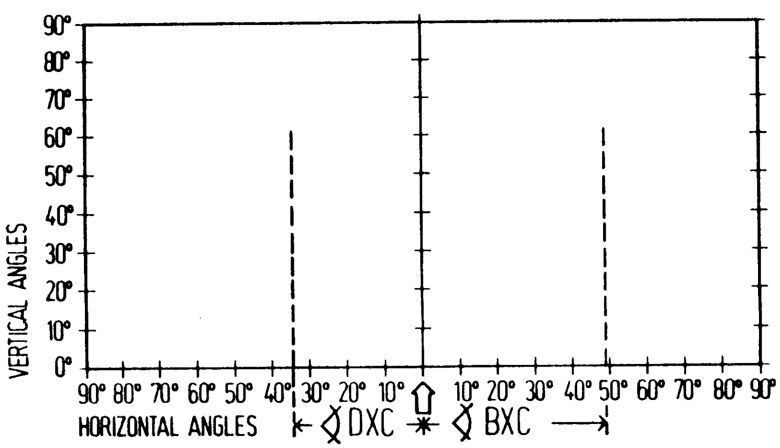


Fig. 30

Step three: Establish the corresponding vertical shadow angles of the court wall opposite to point X along the center-axis (Fig. 31):

Vertical angle $\sphericalangle C_hXC = \tan \frac{\overline{C_hC}}{\overline{C_hX}}$

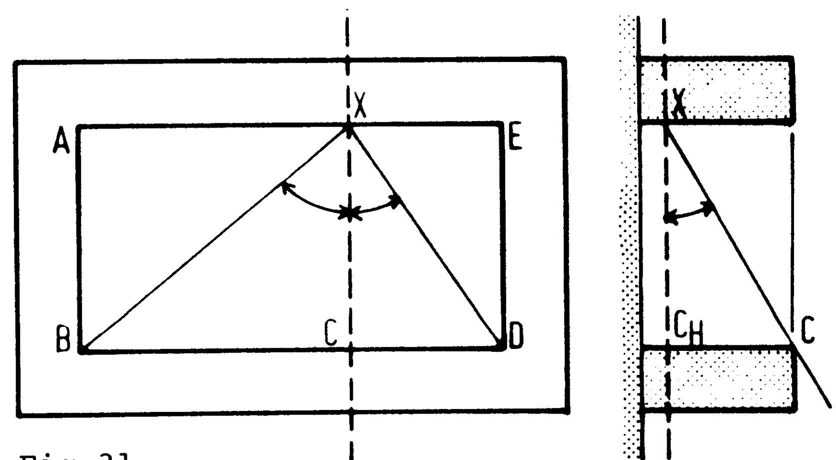


Fig. 31

Step four: Draw horizontal shadow line on the shading mask according to angle $\sphericalangle c_hXC$ by using the preplotted shadow calculator. The center-axis of the shading mask and the shading calculator should be superimposed and their base-lines should be kept aligned (Fig. 32):

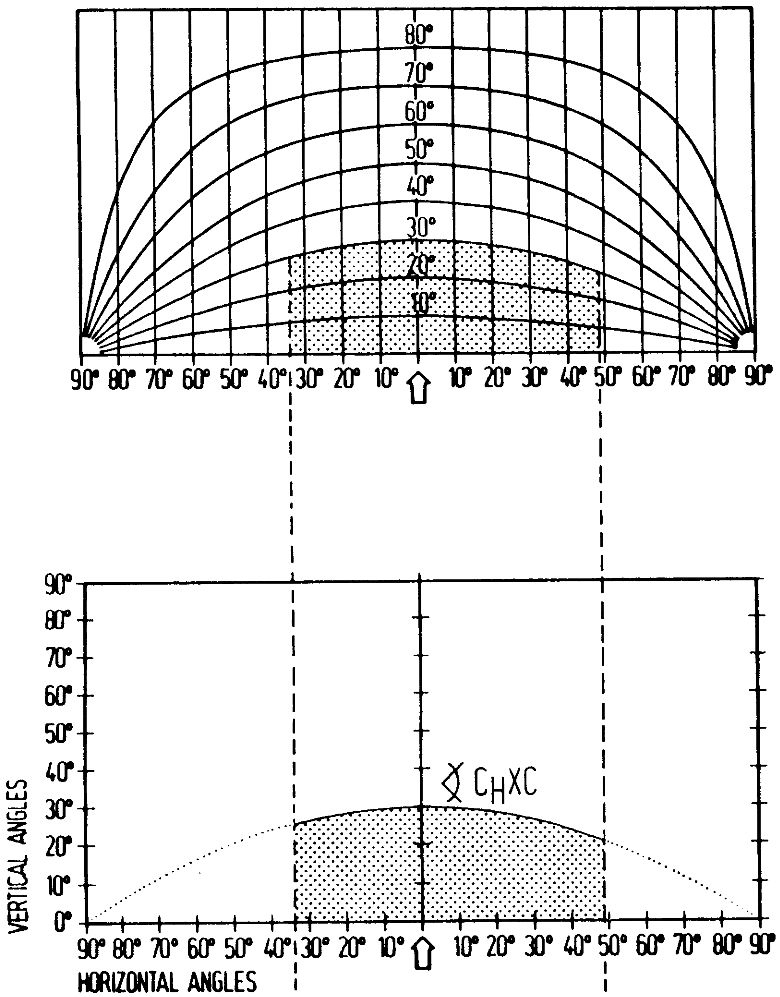


Fig.32

Step five: Establish the corresponding vertical shadow angles of the side court-wall-corners left and right to point X:

Vertical angles $\sphericalangle E_hXE = \tan \dfrac{\overline{E_hE}}{\overline{E_hX}}$

$$A_hXA = \tan \frac{\overline{A_hA}}{\overline{A_hX}}$$

Step six: Mark vertical angles on the according 90° side-lines of the shading mask; $\sphericalangle E_hXE$ on the left 90°-side-line and $\sphericalangle A_hXA$ on the right 90°-side-line (Fig. 33):

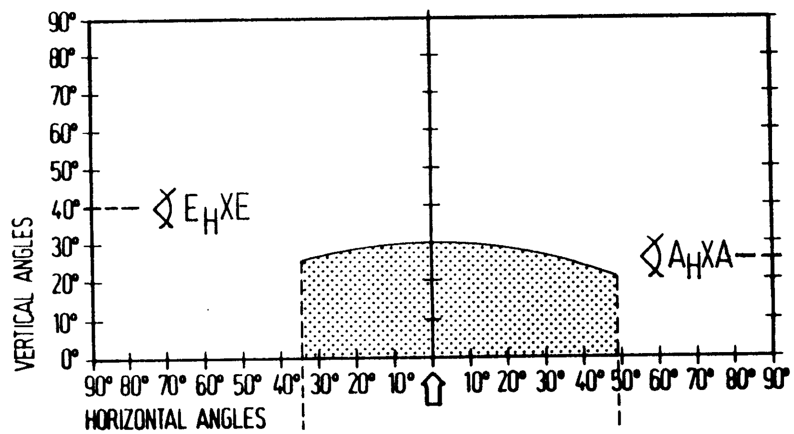


Fig.33

Step seven: Superimpose the shading mask upon the preplotted shadow calculator so that one after the other of the 90° side-lines is aligned with the center-axis of the shadow calculator. Draw the horizontal shadow lines (Fig. 34):

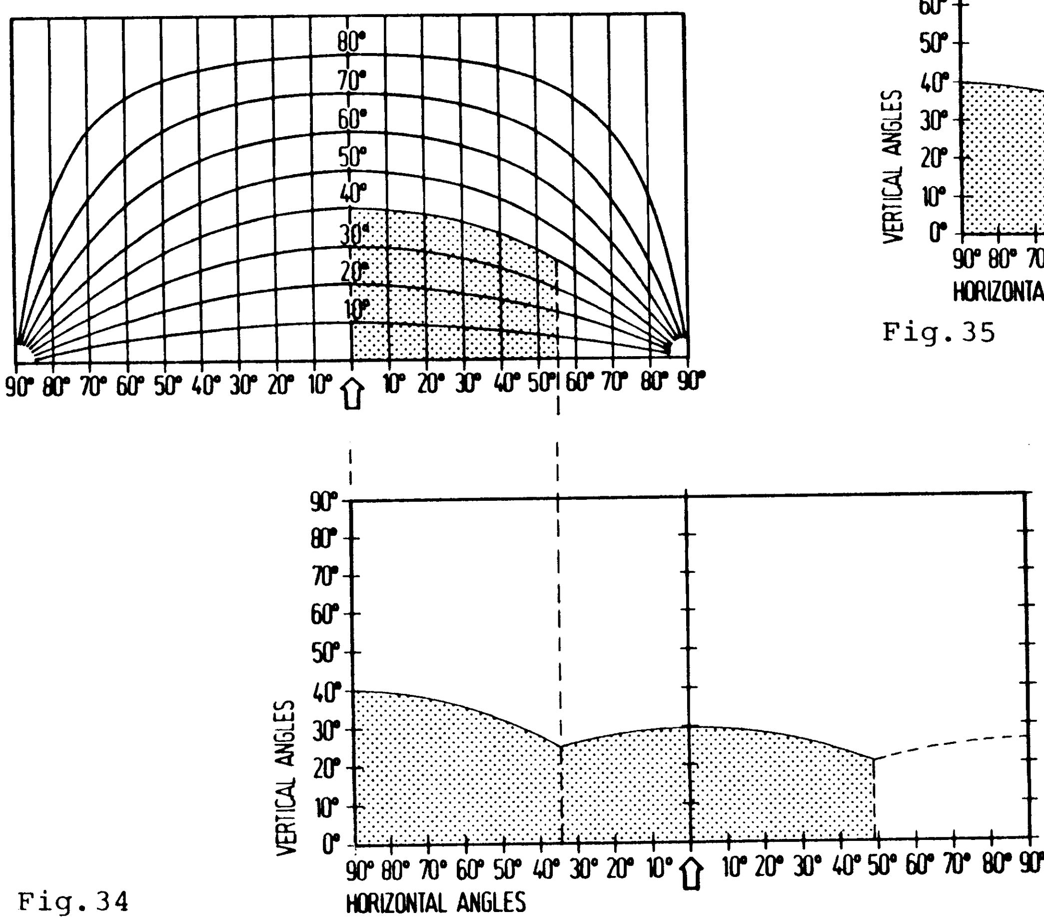


Fig. 34

The final image of the constructed shadow mask might look like Fig. 35.

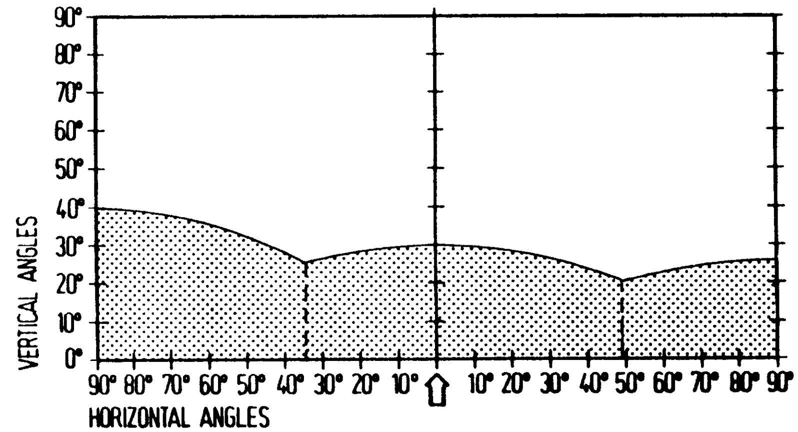
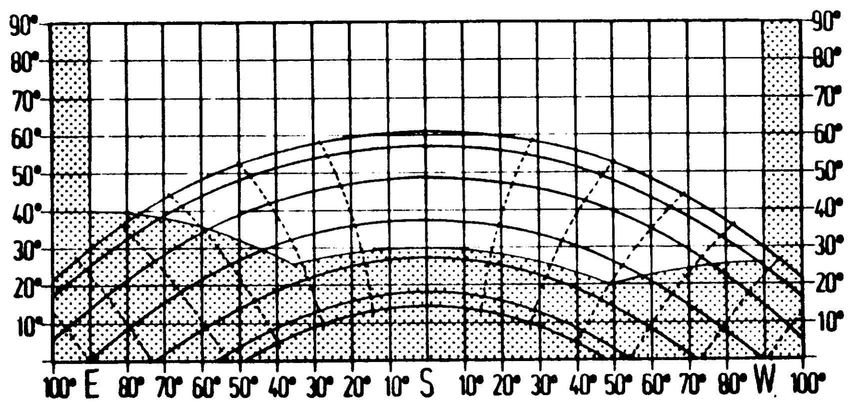


Fig. 35

Step eight: Superimpose the shading mask upon the sun chart for 52° north latitude. Use the center-axis and the base-line to align it with the sun chart. This is true if the observation point X faces due south. If the direction of the surface is off due south than keep the base-lines aligned and shift the pointer of the shadow mask to line up with the actual amount of degrees the surface faces to east or west of due south (maximum: +10° to -10°).



Now we can directly note the time during which solar radiation is intercepted by this particular vertical southfacing surface at each month of the year.

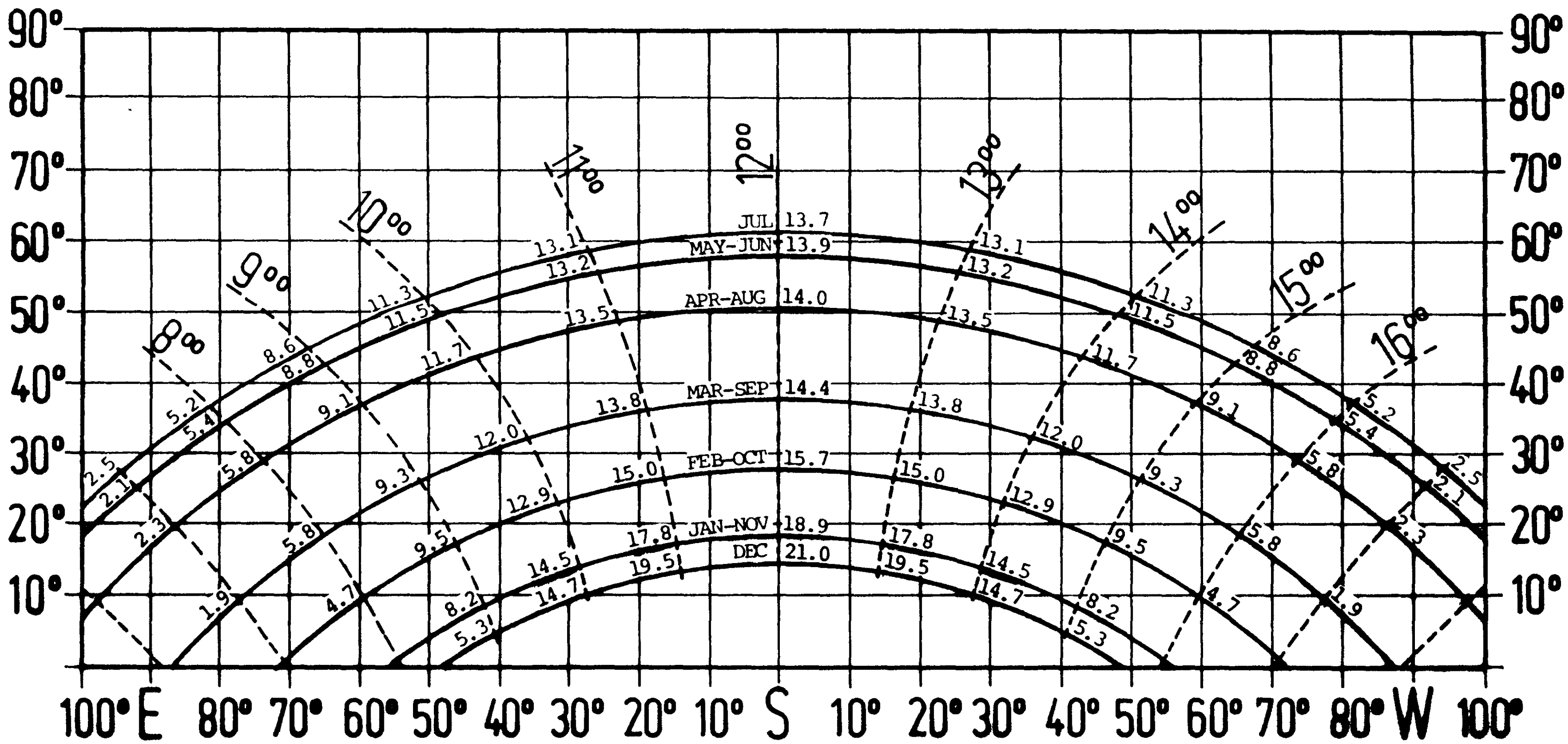
But it doesn't show us the amount of solar radiation reaching the surface.

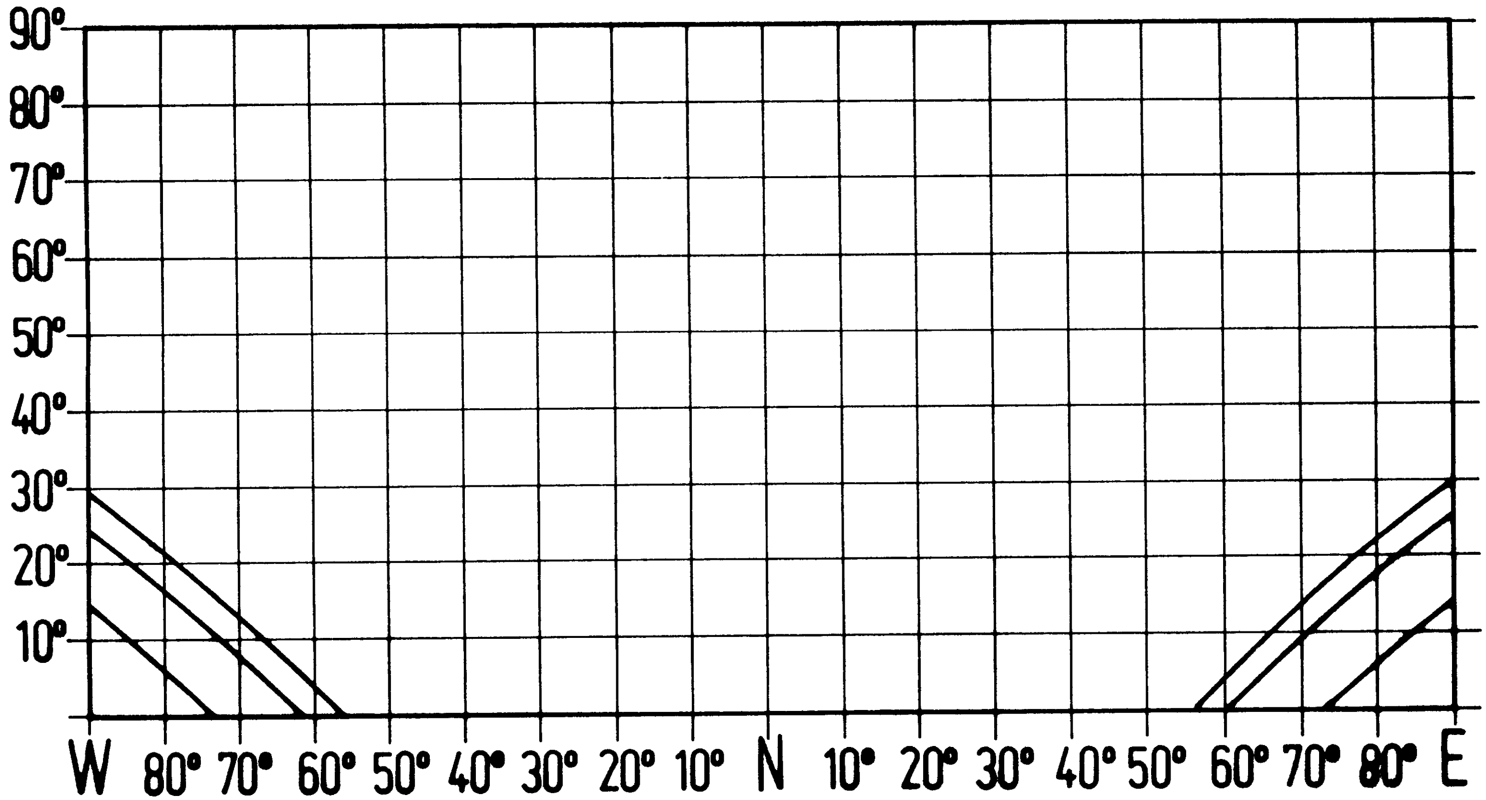
Therefore the sun chart is modified (Fig. 36) to show the actual yearly percentages of the total daily insolation intercepted by the surface in question. The figures transposed on the sun chart relate to the percentage of hourly solar radiation striking a vertical southfacing surface at point X. Basic calculations to obtain these percentages were done with Chris Benton's TI-59 program "Daily Profile Solar Angles & Radiation" (MIT, May 1978). All printouts are presented in Appendix B. Adding up the percentages of each hour (without the shaded times) for a certain month gives you the total percentage of intercepted radiation for that surface and for that particular month.

Similar to the sun chart representing the southern half of the sky vault, a chart (called N-chart) can be developed to represent the northern half of the sky vault (see page 61).

Superimposed with a shading mask showing obstructions of a north facing window one can determine

Fig.36 Percentage of daily totals of solar irradiation on vertical southfacing surfaces for clear day conditions (atmospheric clearance factor = 0.85). Values are given for the 21. of each month.




90°
80°
70°
60°
50°
40°
30°
20°
10°
W 80° 70° 60° 50° 40° 30° 20° 10° N 10° 20° 30° 40° 50° 60° 70° 80° E

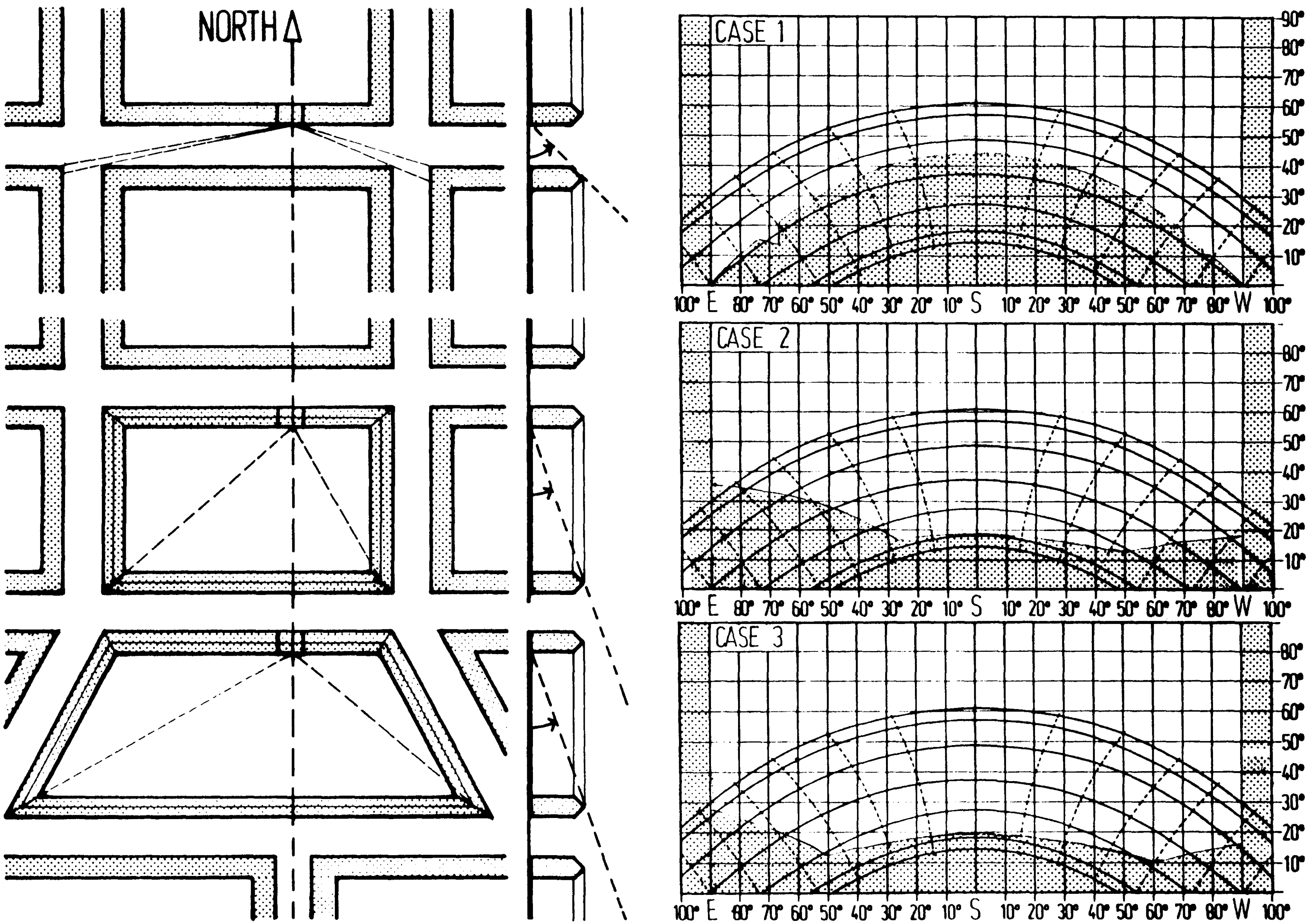
the amount of diffuse radiation reaching the window. (The small amounts of direct radiation on summer mornings and evenings are neglectable, a uniform sky vault is assumed.) The diffuse radiation on a surface is directly proportional to the portion of sky vault seen by the surface. For example, a vertical surface sees only half the sky hemisphere if there are no other obstructions.
The northern half of the sky vault is divided in 9x18=162 equal squares (see N-CHART). The surrounding obstructions cover a certain amount of these squares which can then be counted. Dividing the number of obstructed squares (N) by the total number of squares (168) results in the percentage of obstructed sky vault. Multiplicated with half (northern half of the sky vault) of the monthly diffuse radiation it shows the actual radiation striking a vertical north-facing surface (window or wall):

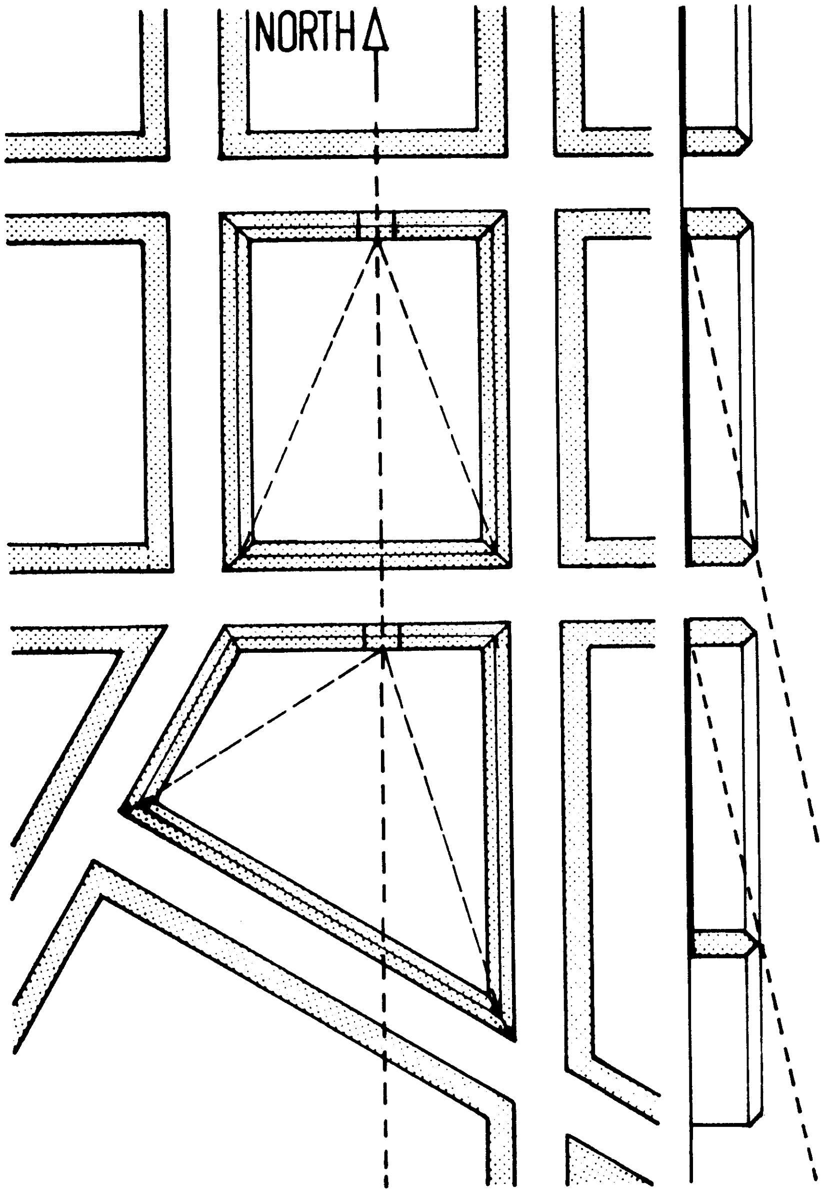
$$\left(1 - \frac{N}{168}\right) \times \frac{\text{monthly dif. rad.}}{2} = \begin{matrix}\text{dif. radiation}\\ \text{intercepted}\end{matrix}$$

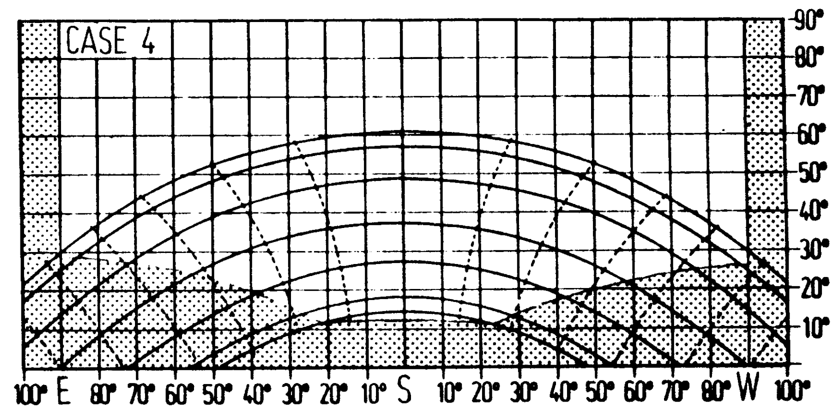
This method of calculating the percentage of unobstructed sky vault can also be used for calculations concerning the amount of diffuse radiation intercepted by a southfacing surface.

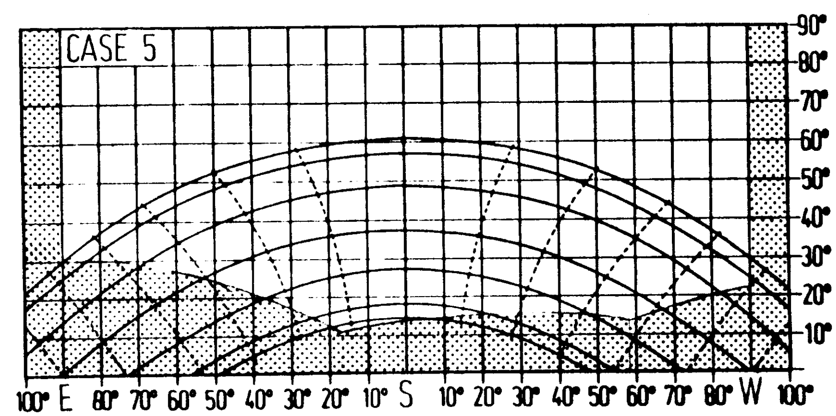
Solar Availability versus City Layout

Dealing with the given street and block patterns of Berlin's urban settlement puts some constraints on choosing proper sites for solar use.
Orientation of the building:
The building in question should face almost directly south ($\pm 30^{o}$) to make the most out of the available solar radiation. This is true for quite a number of block-buildings as a short look over the map of Berlin shows.
Shape and size of the block:
The width of streets and blocks should be large enough to allow sufficient solar access during the winter months. For a number of blocks this means to partly clear out the interior courtyards from back-buildings in order to intercept solar radiation by the lower floors during winter months. A range of different block sizes is shown on the next two pages. The according shadow masks are constructed and superimposed with the sun chart for 52^{o} north latitude.


NORTH
CASE 1
CASE 2
CASE 3
90°
80°
70°
60°
50°
40°
30°
20°
10°
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°


NORTH


CASE 4
90°
80°
70°
60°
50°
40°
30°
20°
10°
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°


CASE 5
90°
80°
70°
60°
50°
40°
30°
20°
10°
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°

The following table provides average daily values of solar radiation intercepted per 1m^2 of vertical southfacing surface (= before transmission) for Berlin-Dahlem.

- "diffuse (actual)" stands for 50% (=southern sky valut) of the total diffuse radiation available on an average day of a particular month.
- "global (actual)" is the average daily total insolation (diffuse and direct) striking 1m^2 of vertical southfacing surface, calculated with given actual values assuming 0.3 ground reflectance. A TI-59 program "Average Daily Radiation III" by Jim Rosen (MIT, Jan. 1980) was used to generate these values. All printouts are presented in Appendix C .
- "global (clear day)" is the daily insolation under clear day conditions - atmospheric clearance factor = 0.85 - intercepted by 1m^2 of vertical southfacing surface at 52^{o}North Latitude. Values were calculated by using Chris Benton's TI-59

	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x = Wh/m^2	359Wh/m^2 x = Wh/m^2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m2	1252Wh/m^2 x = Wh/m^2	1371Wh/m^2 x = Wh/m^2
global (actual)	1130Wh/m^2 x = Wh/m^2	1622Wh/m^2 x = Wh/m^2	2500Wh/m^2 x = Wh/m^2	2525Wh/m^2 x = Wh/m^2	2892Wh/m^2 x = Wh/m^2	2992Wh/m^2 x = Wh/m^2
global (clear day)	3615Wh/m^2 x = Wh/m^2	4803Wh/m^2 x = Wh/m^2	5069Wh/m^2 x = Wh/m^2	4465Wh/m^2 x = Wh/m^2	3928Wh/m^2 x = Wh/m^2	3720Wh/m^2 x = Wh/m^2

	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m^2 x = Wh/m^2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x = Wh/m^2	178Wh/m^2 x = Wh/m^2
global (actual)	3024Wh/m^2 x = Wh/m^2	3143Wh/m^2 x = Wh/m^2	2953Wh/m^2 x = Wh/m^2	2162Wh/m^2 x = Wh/m^2	1260Wh/m^2 x = Wh/m^2	863Wh/m^2 x = Wh/m^2
global (clear day)	3853Wh/m^2 x = Wh/m^2	4300Wh/m^2 x = Wh/m^2	4788Wh/m^2 x = Wh/m^2	4563Wh/m^2 x = Wh/m^2	3237Wh/m^2 x = Wh/m^2	2956Wh/m^2 x = Wh/m^2

Program "Daily Profile Solar Angles & Radiation" (MIT, May 1978). All printouts are presented in Appendix B.

The next two pages show the use of this table in conjunction with shading conditions of three different court-yard situations (case 1-3) described on the previous pages. The first row (diffuse-actual) only applies during months where no global (= diffuse and direct) radiation is intercepted.

CASE 1	January	February	March	April	May	June
diffuse (actual)	237Wh/m² x .67 = 159 Wh/m²	359Wh/m² x .67 = 241 Wh/m²	706Wh/m² x .67 = 473 Wh/m²	984Wh/m² x = Wh/m²	1252Wh/m² x = Wh/m²	1371Wh/m² x = Wh/m²
global (actual)	1130Wh/m² x = Wh/m²	1622Wh/m² x = Wh/m²	2500Wh/m² x = Wh/m²	2525Wh/m² x .98 = 2475 Wh/m²	2892Wh/m² x .95 = 2747 Wh/m²	2992Wh/m² x .93 = 2783 Wh/m²
global (clear day)	3615Wh/m² x = Wh/m²	4803Wh/m² x = Wh/m²	5069Wh/m² x = Wh/m²	4465Wh/m² x .98 = 4376 Wh/m²	3928Wh/m² x .95 = 3732 Wh/m²	3720Wh/m² x .93 = 3460 Wh/m²

CASE 1	July	August	September	October	November	December
diffuse (actual)	1369Wh/m² x = Wh/m²	1117Wh/m² x = Wh/m²	810Wh/m² x .67 = 543 Wh/m²	492Wh/m² x .67 = 330 Wh/m²	271Wh/m² x .67 = 182 Wh/m²	178Wh/m² x .67 = 119 Wh/m²
global (actual)	3024Wh/m² x .95 = 2873 Wh/m²	3143Wh/m² x .98 = 3080 Wh/m²	2953Wh/m² x = Wh/m²	2162Wh/m² x = Wh/m²	1260Wh/m² x = Wh/m²	863Wh/m² x = Wh/m²
global (clear day)	3853Wh/m² x .95 = 3660 Wh/m²	4300Wh/m² x .98 = 4214 Wh/m²	4788Wh/m² x = Wh/m²	4563Wh/m² x = Wh/m²	3237Wh/m² x = Wh/m²	2956Wh/m² x = Wh/m²

CASE 2	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x .77 = 182 Wh/m^2	359Wh/m^2 x = Wh/m2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m2	1252Wh/m^2 x = Wh/m^2	1371Wh/m^2 x = Wh/m^2
global (actual)	1130Wh/m^2 x = Wh/m^2	1622Wh/m^2 x .80 = 1298 Wh/m^2	2500Wh/m^2 x .89 = 2225 Wh/m^2	2525Wh/m^2 x .90 = 2273 Wh/m^2	2892Wh/m^2 x .95 = 2747 Wh/m^2	2992Wh/m^2 x .92 = 2753 Wh/m^2
global (clear day)	3615Wh/m^2 x = Wh/m^2	4803Wh/m^2 x .80 = 3842 Wh/m^2	5069Wh/m^2 x .89 = 4511 Wh/m^2	4465Wh/m^2 x .90 = 4019 Wh/m^2	3928Wh/m^2 x .95 = 3732 Wh/m^2	3720Wh/m^2 x .92 = 3422 Wh/m^2

CASE 2	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m^2 x = Wh/m2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x .77 = 209 Wh/m^2	178Wh/m^2 x .77 = 137 Wh/m^2
global (actual)	3024Wh/m^2 x .95 = 2873 Wh/m^2	3143Wh/m^2 x .90 = 2829 Wh/m^2	2953Wh/m^2 x .89 = 2628 Wh/m^2	2162Wh/m^2 x .80 = 1730 Wh/m^2	1260Wh/m^2 x = Wh/m^2	863Wh/m^2 x = Wh/m^2
global (clear day)	3853Wh/m^2 x .95 = 3660 Wh/m^2	4300Wh/m^2 x .90 = 3870 Wh/m^2	4788Wh/m^2 x .89 = 4261 Wh/m^2	4563Wh/m^2 x .80 = 3650 Wh/m^2	3237Wh/m^2 x = Wh/m^2	2956Wh/m^2 x = Wh/m^2

CASE 3	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x .82 = 194 Wh/m^2	359Wh/m^2 x = Wh/m2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m2	1252Wh/m^2 x = Wh/m^2	1371Wh/m^2 x = Wh/m^2
global (actual)	1130Wh/m^2 x = Wh/m^2	1622Wh/m^2 x .89 = 1444 Wh/m^2	2500Wh/m^2 x .95 = 2375 Wh/m^2	2525Wh/m^2 x .97 = 2449 Wh/m^2	2892Wh/m^2 x .96 = 2776 Wh/m^2	2992Wh/m^2 x .93 = 2783 Wh/m^2
global (clear day)	3615Wh/m^2 x = Wh/m^2	4803Wh/m^2 x .89 = 4275 Wh/m^2	5069Wh/m^2 x .95 = 4816 Wh/m^2	4465Wh/m^2 x .97 = 4331 Wh/m^2	3928Wh/m^2 x .96 = 3771 Wh/m^2	3720Wh/m^2 x .93 = 3460 Wh/m^2

CASE 3	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m^2 x = Wh/m2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x .82 = 222 Wh/m^2	178Wh/m^2 x .82 = 146 Wh/m^2
global (actual)	3024Wh/m^2 x .96 = 2903 Wh/m^2	3143Wh/m^2 x .97 = 3049 Wh/m^2	2953Wh/m^2 x .95 = 2805 Wh/m^2	2162Wh/m^2 x .89 = 1924 Wh/m^2	1260Wh/m^2 x = Wh/m^2	863Wh/m^2 x = Wh/m^2
global (clear day)	3853Wh/m^2 x .96 = 3699 Wh/m^2	4300Wh/m^2 x .97 = 4171 Wh/m^2	4788Wh/m^2 x .95 = 4549 Wh/m^2	4563Wh/m^2 x .89 = 4061 Wh/m^2	3237Wh/m^2 x = Wh/m^2	2956Wh/m^2 x = Wh/m^2

CHAPTER 4

URBAN TENEMENT HOUSING IN WEST-BERLIN

Fig.37 Plan of Berlin by Peter Joseph Lenne (1840)

Historical Development of Berlin's Street and Building Patterns

The fast growth of Berlin's population during the 19th century required the provision of sufficient housing. The city had to cope with almost half a million inhabitants in the mid-century, 827 000 in early 1871 and 1 800 000 at the turn of the century. Early masterplans (Peter Lenne)[32]couldn't manage to channel the enormous expansion of the city's population (see Fig.37). Extreme demand for housing led to highest density construction.

Increasing hygenic, health and fire-safety problems called for legislative actions. Early regulations like the Bauordnung von 1641" provided the basis for a series of new building codes, c.f. the "Baupolizeiverordnung von 1853" - which were instituted by the police president of Berlin. Their main purpose was to protect real estate from fire damage as well as to insure certain basic health standards (air and light) for Berlin's inhabitants. Besides this, the new building codes provided neighboring rights and deeds. It virtually legalized already existing high densitv built-up of city areas.

In 1858 the Minister of Trade, Industry and Public Works asked Baurat James Hobrecht to design a masterplan for the city's further development (see Fig.38). The aim was to provide a layout for a projected population of 4 000 000. A large grid was chosen for the street plan because the city had to pay for all street construction whereas subdivisions were intended to be privately financed. These subdivisions never took place. This led to large block-structures which had to be filled with several layers of court yard buildings to exploit as much as possible of the available space. A first addition to the building code of 1853 followed in 1860. In 1887 the first revision was due: failures and mistakes of the previous codes had been recognized and some attempts were made to improve the situation of tenement housing, but they often came too late to have impact on the completely built-up city areas.

Excerpts from these building codes will show their direct impact on block-patterns.[33,34,35,]

Fig. 38 Plan of Berlin by James Hobrecht (1862)

Police Building Code of April 21., 1853

Street lines:
The police president determines the street-lines.

Access:
building permit only if there is a driveway with a width of 5.34m to the public street or place.

Thoroughfare:
buildings with a depth of more than 31.4m need a thoroughfare of 2.51m width and 2.83m height for the fire-truck.

Balconies:
cannot project more than 1.88m in front of the street line and cannot be lower than 3.14m above the pedestrian walkway. Minimum distance from the neighbor building has to be 1.57m.

Building height:
uniform height of 11.30m for all street buildings if the street is not wider than 11.30m. For street width from 11.30m to 15.07m the permissible building height is 1,25 times the street width. Minimum height of living units is 2.51m.

Courtyard:
minimum size is 5.60m x 5.60m = 31.36m^2
(in 1887: 60m^2
in 1897: 80m^2)

Police Building Code of March 12., 1860

Building height:
buildings higher than 11.30m should have a height similar to the street's width, but not higher.

Building distances:
buildings on the same site require a minimum distance of 5.34m one from another.

Courtyards:
minimum size is 5.34m x 5.34m = 28/52m^2

Masterplan of James Hobreacht, 1863:

Width of streets was fixed at a minimum of 22m. The length of the rectangular blocks could reach 500m.

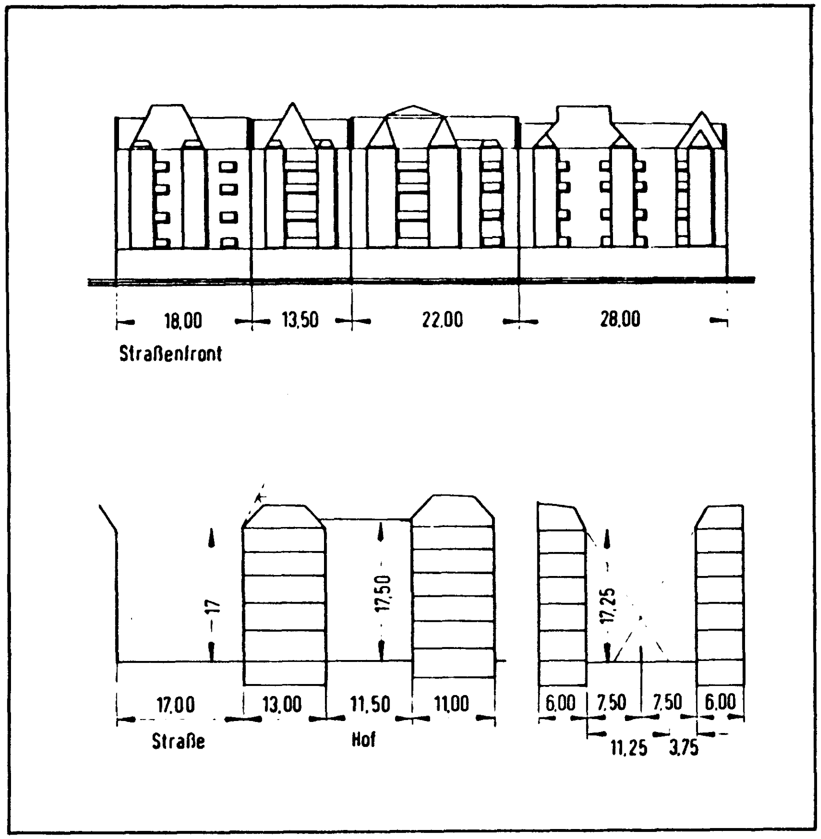
Police Building Code of June 15., 1887

All previous orders are still valid for the entire city. Changes were made in the following areas:

Building height:

12m height for all street buildings if the street is not wider than 12m.
Higher buildings must choose the appropriate height according to the street's width up to a maximum height of 22m. Above 22m one could build a pitched roof with a maximum angle of 45° above horizontal.
The height of the backyard houses could exceed the depth of the courtyard by max. 6m.

A set of typical building plans, reflecting these building codes is presented below (Fig. 39 and 40):



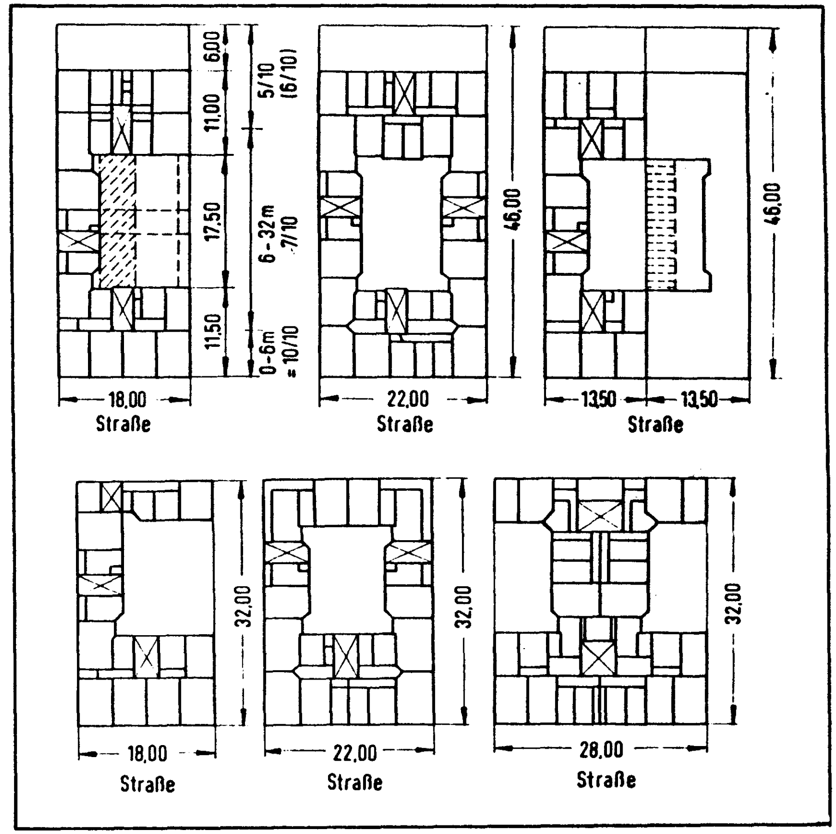


Fig. 39 Typical street facade and section

Fig. 40 Typical floorplans

Source: "Berlin und seine Bauten" Part IV Wohnungsbau - Volume A

Evolution of Urban Renewal Strategies in Berlin

A first phase of inofficial renewal of the Berlin housing stock can be noted right after the war up to 1950. Destroyed and run down property was provisionally fixed to provide at least space for housing during an overwhelming shortage. Low quality materials and cheap labor caused poor quality of construction.

The first municipal "urban sanitation-program" came with the re-zoning master plan (use-distribution plan) in the late 1950's, where new residential areas were defined and a reduction of the high urban density was the major goal. This phase, amended with the "Städtebau-Förderungs-Gesetz" essentially eliminated old city tissue, replacing it with modern movement medium rise slabs or substituting it with increased suburban construction. Removing people from the densly built up areas in the city core was considered necessary for reasons of health and comfortable urban life. The goal was completely to rebuild the city with a new "modern" built form of slabs and rowhouses, and to clear up the city for optimal traffic patterns, wider streets and fluid traffic (Fig. 41).

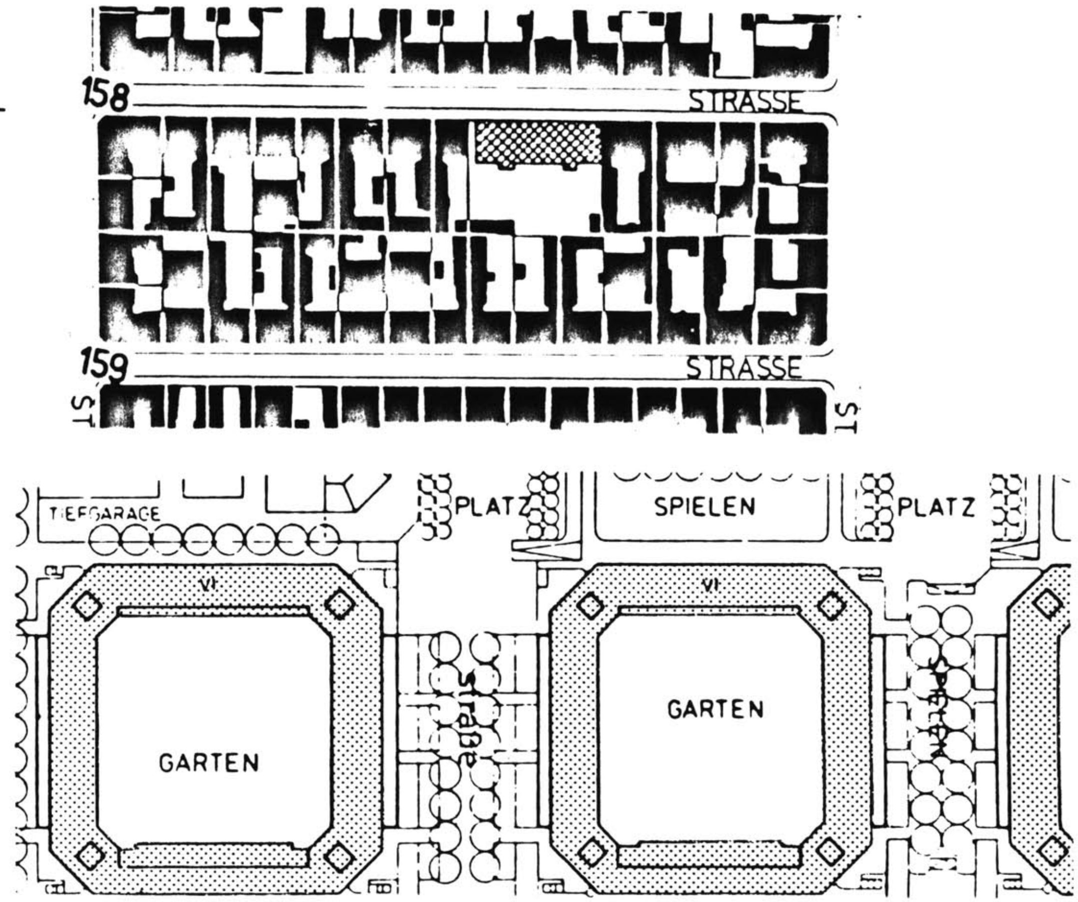


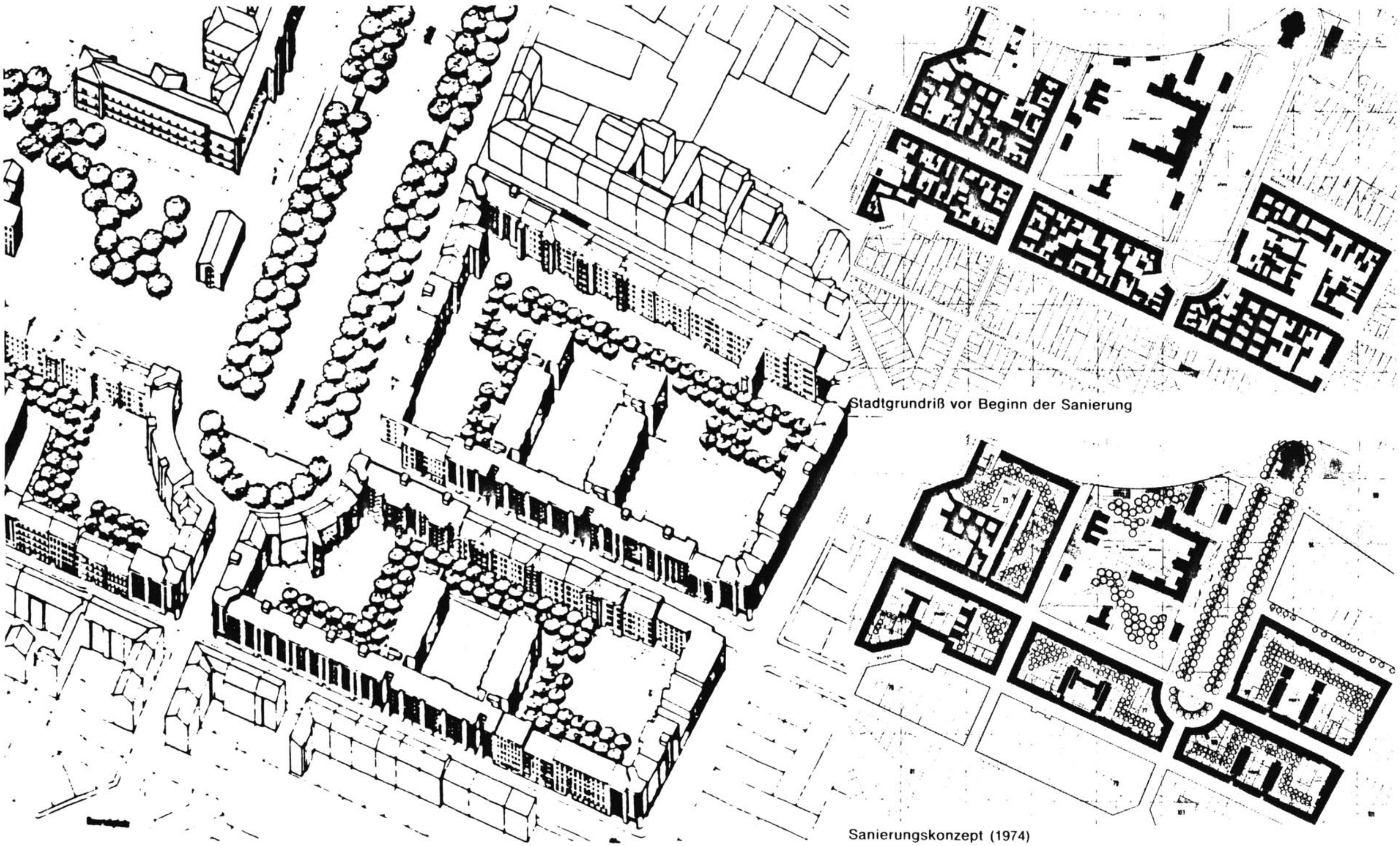
Fig. 41 Sanitation area "Rollberge" in Berlin-Neuköln before sanitation started and proposal for the redesign of the same area

With the mid 60's, this approach was administratively enforced by assigning certain areas of several blocks as "Sanierungs-Gebiet" (sanitation area). The district in question was earmarked for bank loan stop and prergative purchse right of the properties was assigned to renewal construction firms as developers. With this large scale developers came in, forcing the owners to abandon their houses. As a result of this policy, houses deteriorated way beyond actual "time-deterioration." Private owners were intentionally denied their operation margin, and intentionally abandoned houses were sold on lowest fake values.
In fact, an expropriation and maximum gentrification was officially spured for the benefit of developers - with the hope, that their construction capacity and strategy of large districts simultaneously would be able to catch up with the increasing quantity of houses to be renewed.
3000 000 dwellings were projected to become uninhabitable in the next two decades (due to post war jobs and obsolescence).

Gentrification and expropriation led to the first major tenant protests and trials - the origin of the urban action movement, which until the beginning of the 70's brought the "sanitation projects" to nearly full stop, at least to a fatal time lag. Likewise, disadvantages of this approach, failures of the first projects such as the blight of formerly vital city neighborhoods, economical run down areas and skyrocketing rents became so evident, that they posed a major political concern. The abandonment of the city as a historic and livable space was clearly evident and a reconciliation was sought for new urban values. The major projects in Berlin (Rollberge - see Fig.41, Kreuzberg, Wassertorstrasse, Wedding, Charlottenburg) came to a self-defeating stop.

With the turn "back to the city," the next "urban rehabilitation" phase initiated piecemeal renovation of blocks and individual houses (see Fig.42). For this, developer incentives, but also tenant protection amendments were issued (Mod. Inst. Gesetz) to spur a private small scale market as well as to encourage houseowners and small developers to catch up with the still increasing reno-

Fig. 42



Stadtgrundriß vor Beginn der Sanierung

Sanierungskonzept (1974)

vation quantity demands. Additionally, this strategy incorporated infill housing, block and house renovation, and density reduction in gradual ways. The goal was to rebuild the city on the basis and form of existing tissue, to fit new constructions in, and to modernize old structures for future standards.

Encouraged developers, however, exploited finan-ancial incentives, rents tripled easily as a matter of fake accounting of construction jobs into the controlled rent.

While the physical design got back to historic scale, construction activities were dispersed and likewise tenant actions paralysed. Not only big identifiable corporations, but hundreds of small developers controlled the housing market and put pressure on real estate values.

The administrative control of this obviously got out of hand. A new city wide - not area related - action movement responded beginning in 1975, pressing for tenant/owner renovation and for subsidizing owners and tenants directly rather than public subsidizing of developers.

Preservation

Since January 1978 the city of Berlin has had an improved regulation dealing with preservation issues. It enables the city to protect buildings, building areas and park areas from changes if they are of historical, artistic or scientific value and if they are significant for the city image. Historical buildings are listed and no changes in appearance or usage can be made without the permission of the Commissionar of Historical Preservation. If changes are necessary they have to match the character of surrounding existing buildings, such as street fronts, proportion of facades and roof slopes. This is true for architectural issues as well as for the coloring of facades. Most of the work dealing with the preservation of tenement housing therefore is done for preserving the existing street facades: since 1959 about 550 facades have been restored under city grants. Two pictures of typical street facades are shown (as they appeared in 1925) in Fig. 43 .

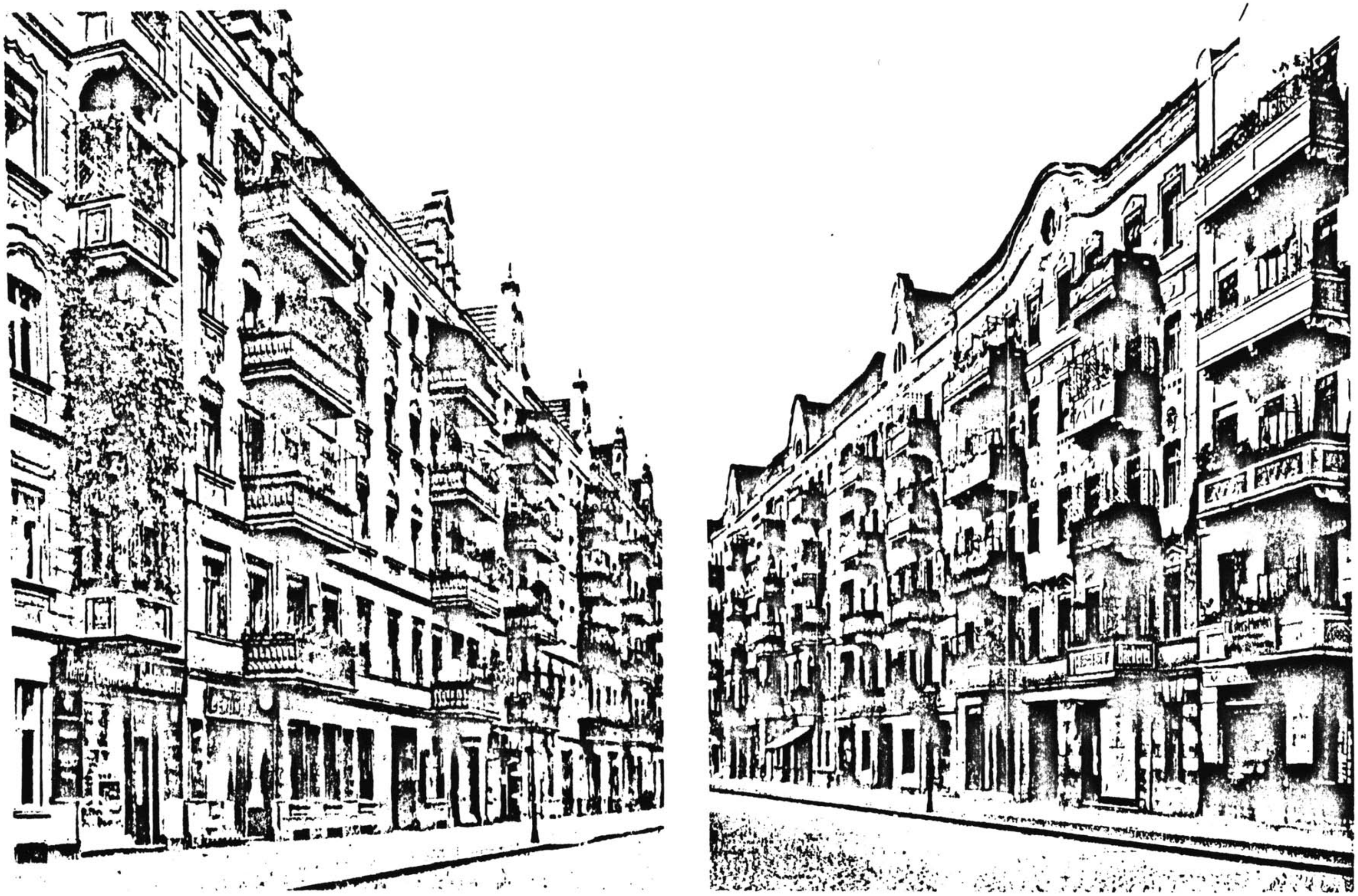


Fig. 43 Street facades in Berlin (1890-1900) [36]

CHAPTER 5

CASE STUDY - EXISTING SITUATION

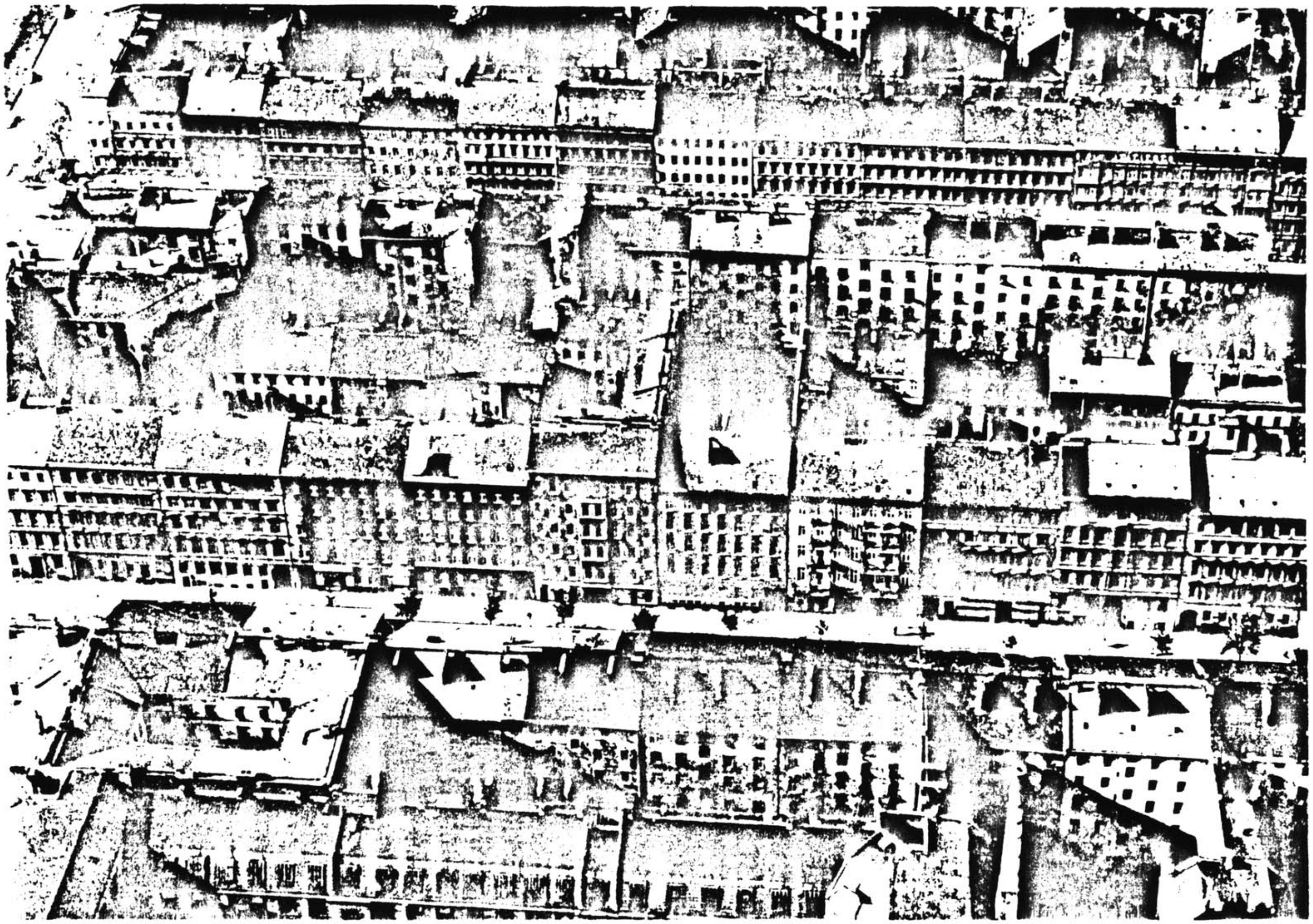


Fig.44 Tenement housing in Berlin-Kreuzberg (1967)

Case Study - Existing Situation

Two generic building types located on the north and south sides of a typical tenement housing block were chosen in order to develop a broader range of possible improvements. The building facing the street north of the block is addressed as "Building A"; the building facing the street south of the block as "Building B" - see Fig. 45 .

Both buildings represent typical outlays of tenement housing structures as shown in Fig.44.

The following set of floorplans, sections through the buildings and street facades describes both types and forms the basis for the redesign.

The fronthouses facing the street always show an amply decorated stucco-facade, are furnished with balconies and baywindows, and try to impress the pedestrian with each single part of their picturesque appearance. Their first floors provide space for all kind of retail shops and have openings serving as thoroughfares to reach the backyards. All other floors in the fronthouse as well as in the backhouses are used as apartments. In general, fronthouse apartments provide more useable floor area than apartments in the backhouses. Each part of the building complex has easy access through several stair wells. Compared with ornate facades of the fronthouses the facades of the backhouse look rather flat and ugly: they only consist of 1 inch of plaster serving as a weather protection for the underlying brick-walls.

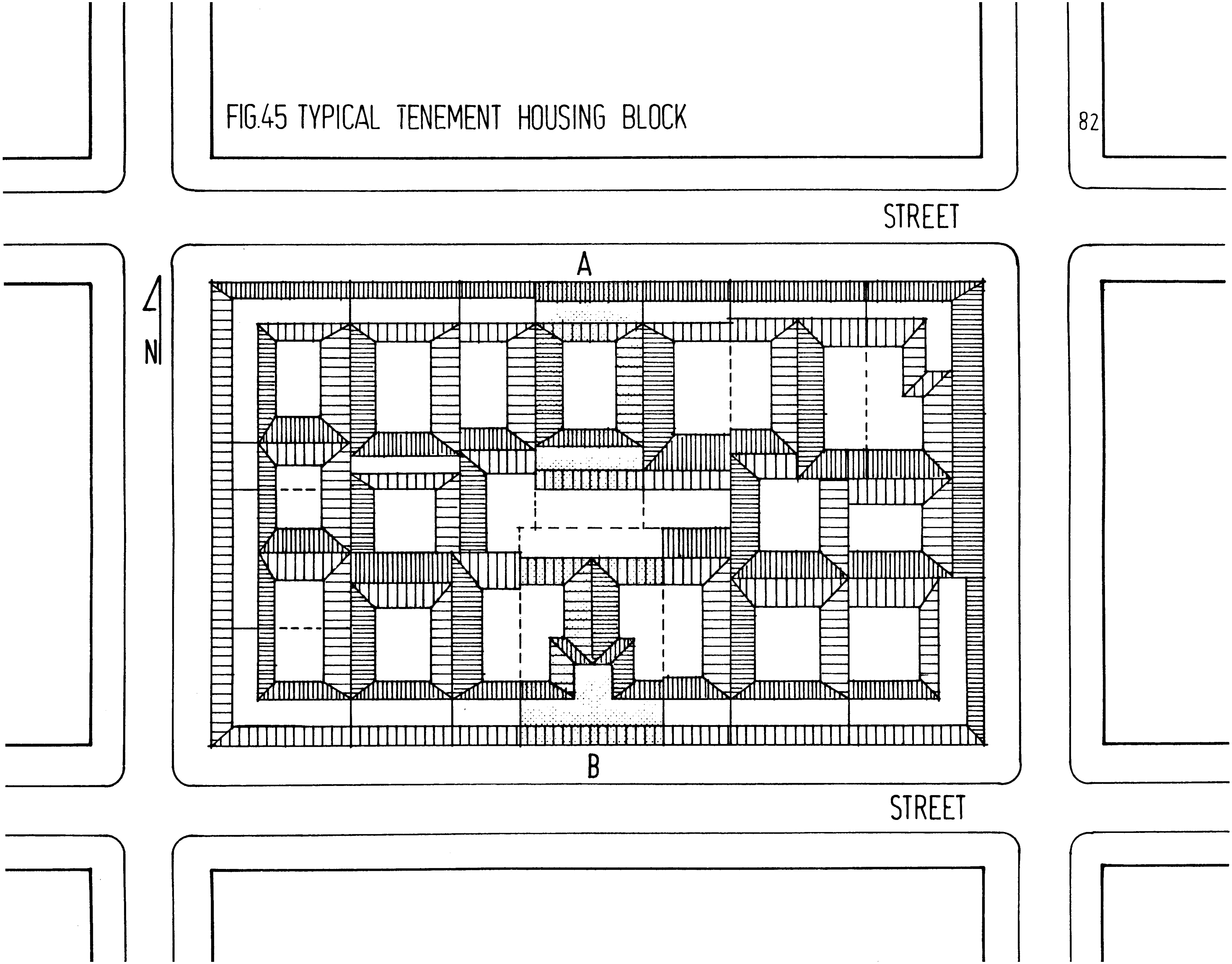
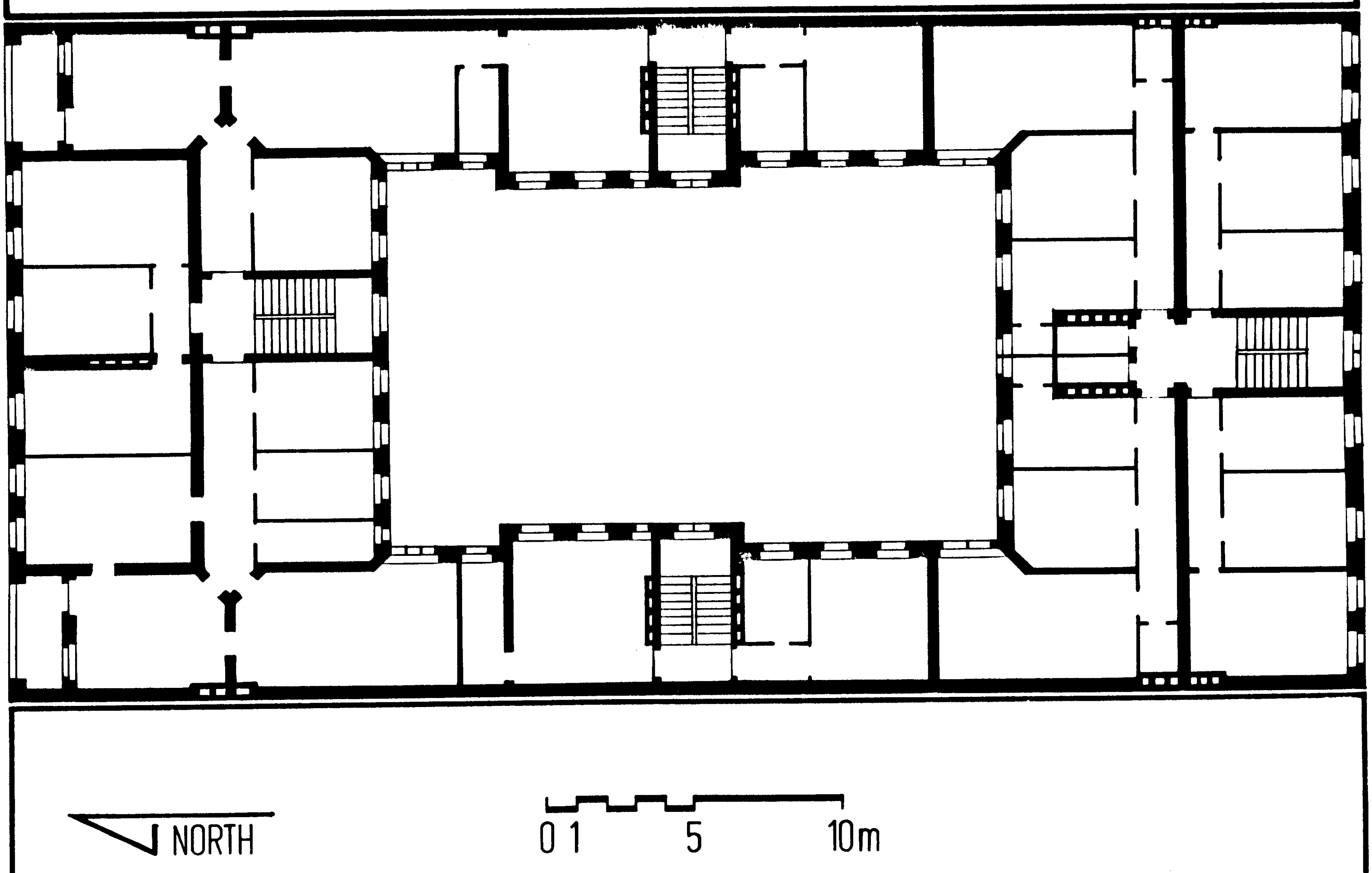


FIG.45 TYPICAL TENEMENT HOUSING BLOCK

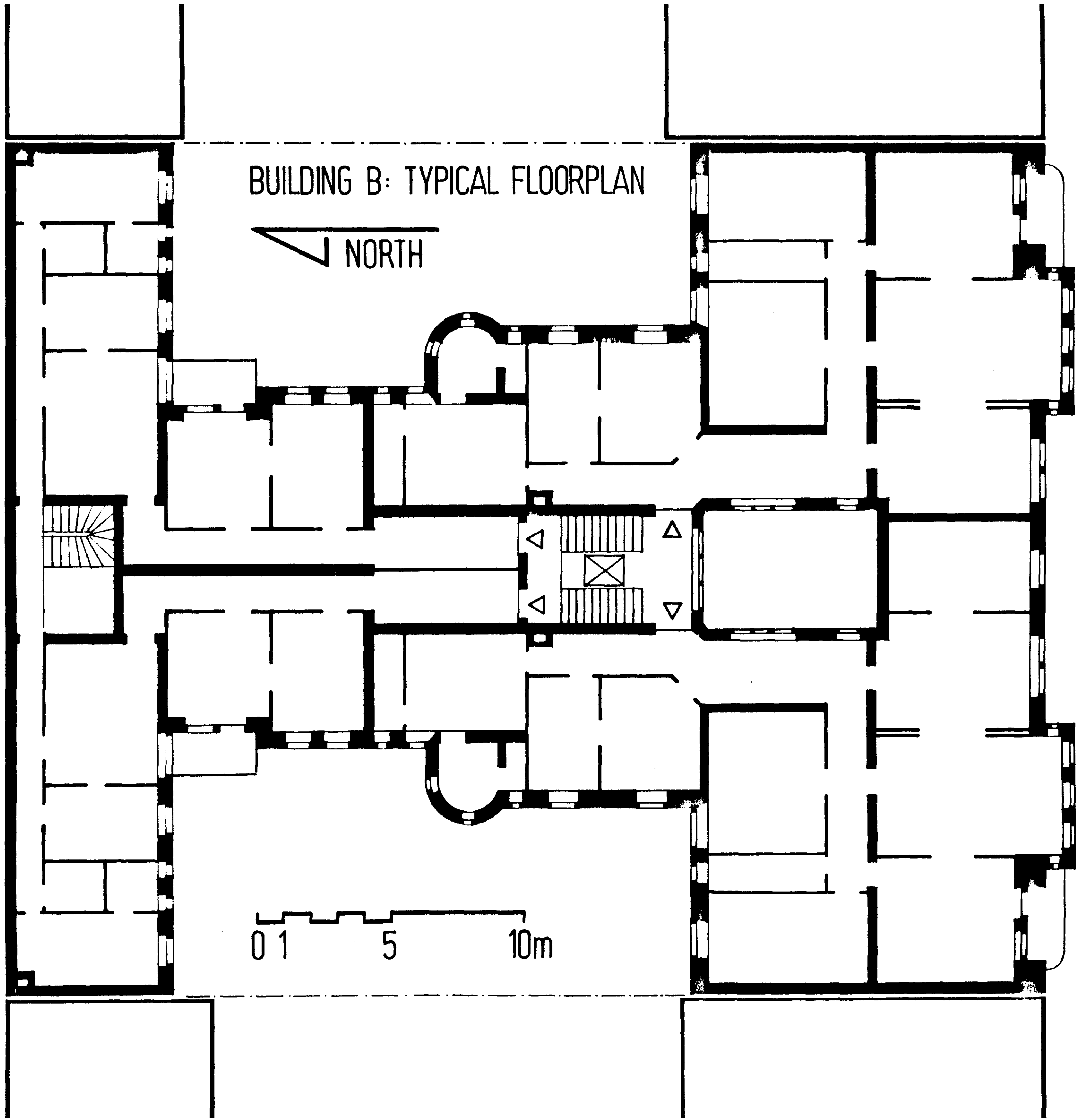
BUILDING A: TYPICAL STREET FACADE

BUILDING A: TYPICAL FLOORPLAN

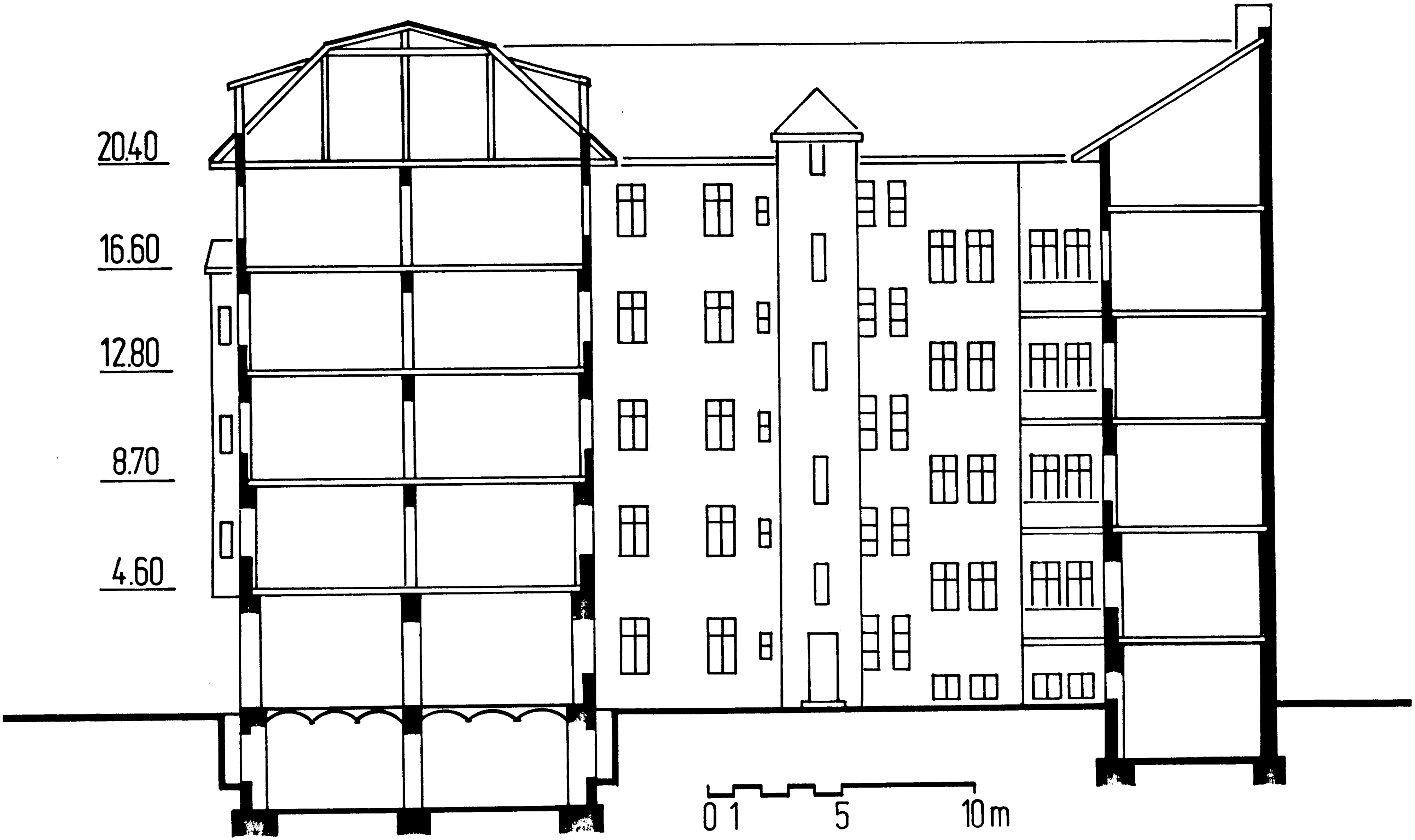


BUILDING A : TYPICAL SECTION

BUILDING B: TYPICAL STREET FACADE


BUILDING B: TYPICAL FLOORPLAN
NORTH
0 1 5 10m

BUILDING B: TYPICAL SECTION



Building Elements

There are three main building elements with which an architect has to deal in order to create comfortable indoor conditions:

1. Exterior walls, affecting heat losses as well as solar heat gains and vapor diffusion.
2. Windows, affecting heat losses and solar heat gain, infiltration and ventilation.
3. Interior walls, floors and ceilings, affecting heat storage and distribution.

Besides those the roof and the basement have to be considered as well. Adequate insulation values for the roof and basement are assumed but will not be discussed in this thesis.

In this case study each existing building element has to be analysed and evaluated. Improvements should lead to an increase in thermal comfort for the residents. Heat losses through transmission and infiltration should be reduced and heat gains should be increased through better use of internal gains and solar gains. Changes in the composition and material of interior and exterior walls, windows, floors and ceilings should be made according to these goals.

Existing Masonry Walls and Possible Improvements

Solid brick-walls are perhaps the oldest type of masonry construction known. They were used extensively in the loadbearing walls of the block structures in Berlin. According to the increase in loads, the thickness of the bearing walls increases as well. The vertical loads are carried by the exterior walls and an interior corridor wall parallel to the exterior wall. The outdoor surfaces of the walls are protected from rain by a layer of plaster. Without any resistance to rain penetration, rain -accompanied by high winds- will penetrate very small openings in the masonry walls and this not only causes annoyance and inconvenience to the occupants but, perhaps more importantly, affects the durability of the masonry: if freezing temperatures occur when masonry is saturated with water, the expansion of the water where frozen will tend to break the masonry apart.

Various problems can arise with building components that are heated by the sun. Expansion and contraction of the object can be increased greatly over the values that would be expected from variations

in ambient air temperature.
Increased movement of walls (windows, roofs) must be allowed for either by suitable clearance or flexibility, or restraints which distribute the stresses so that they can be suitably absorbed.
In winter the number of freeze-thaw cycles to which a wall is subjected will be increased over that of a wall subjected to the same air temperature but not exposed to solar radiation.

This is illustrated in Fig. 46 which shows the variations over a three-day-period (Jan/Feb) of air temperature and corresponding surface temperatures of north- and south-facing walls of a test building constructed of brick and located on Ottawa, Canada (46° North Latitude)[37].
The temperature of the southfacing brick-wall rose above and fell below 0°C, causing a thaw-freeze cycle in the brickwork. The air temperature remained below 0°C, as did the temperature of the northfacing brick-wall. For the south wall this might generate a set of problems: Cracks might occur, capillary forces might draw water into the brick and thereby lower its thermal resistance, and cracks might cause higher infiltration losses.

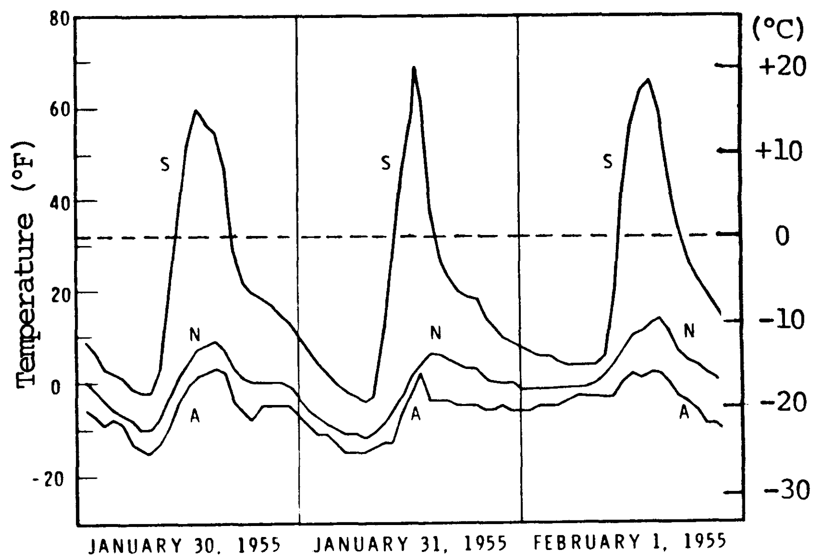


Fig. 46 Effect of solar radiation on the surface temperature of a south-facing (S) brick wall as compared with a north-facing (N) wall and air temperature (A)

Quite a few of the existing street facades in Berlin are historically preserved. Thus, any improvement of the thermal properties of these walls can only be done on their interior side.
Basis for any improvement is solid knowledge about the existing walls as well as understanding the advantages and disadvantages of improving measures.
The k-values of all upper exterior walls are far below (or just matching) the standard values, required by the official energy standards (Wärmeschutzverordnung vom 11.8.77):

k_{max} of window & walls $= 1.75\ W/m^2K$, which leads after subtracting the k-value of 25% double glazing to a k_{max} of wall $= 1.25\ W/m^2K$
- see following page.

Heat Flow through Existing Walls

Heat loss or transmittance through a wall is measured in terms of its k-value which is the amount of heat in Watt transmitted per $1m^2$/of wall per 1^oK temperature difference between inside and outside air temperature for steady state conditions. The k-value itself is the reciprocal of the sum of all resistances of all materials and surface air films of a composite wall:

$$K\text{-value} = \frac{1}{R_1 + R_2 + R_3 + \ldots R_n}$$

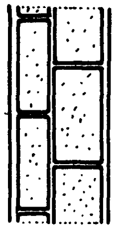
The k-values for the walls in the case study are computed in Fig. .
The temperature gradient through a wall can be calculated following the arithmetic method given below:

$$t_x = \frac{R}{\Sigma R} \times (t_i - t_o)$$

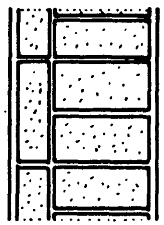
The drop in temperature through any wall component equals:

$$= \frac{\text{Thermal resistance of component}}{\text{Total thermal resistance of wall}} \times (t_{indoor} - t_{outdoor})$$

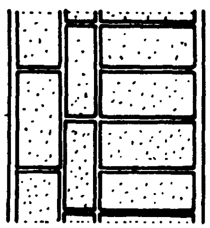
EXISTING WALL CONSTRUCTION



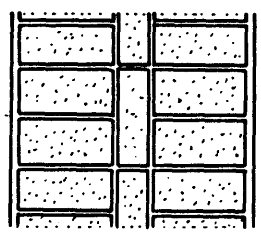
ATTIC



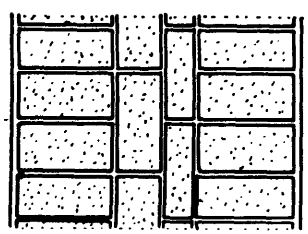
5.+4. FLOOR



3.+2. FLOOR



1. FLOOR



BASEMENT UNINHABITABLE

		Thickness (m)	Density (kg/m³)	Resistance (m^2K/W)	k - Value (W/m^2K)	Temp.drop. (°C)	Interface T. (°C)
ATTIC							-10.0° outdoor t.
	1. Outside surface (2 m/sec)	-	-	0.04		2.5°	- 7.5°
	2. Plaster	0.02	2100	0.015		1.0°	- 6.5°
	3. Brick	0.21	1800	0.266		16.8°	10.3°
	4. Plaster	0.02	1900	0.023		1.5°	11.8°
	5. Inside surface (still air)	-	-	0.13		8.2°	20.0° indoor t.
	Total wall	0.25		0.474	2.11	Δt: 30°C	
5.+4. FLOOR	1. Outside surface (2 m/sec)	-	-	0.04		1.9°	- 8.1°
	2. Plaster	0.02	2100	0.015		0.7°	- 7.4°
	3. Brick	0.34	1800	0.430		20.2°	12.8°
	4. Plaster	0.02	1900	0.023		1.1°	13.9°
	5. Inside surface (still air)	-	-	0.13		6.1°	
	Total wall	0.38		0.638	1.57	Δt: 30°	
3.+2. FLOOR	1. Outside surface (2 m/sec)	-	-	0.04		1.5°	- 8.5°
	2. Plaster	0.02	2100	0.015		0.6°	- 7.9°
	3. Brick	0.47	1800	0.595		22.2°	14.3°
	4. Plaster	0.02	1900	0.023		0.9°	15.2°
	5. Inside surface (still air)	-	-	0.13		4.8°	
	Total wall	0.51		0.803	1.25	Δt: 30°C	
1. FLOOR	1. Outside surface (2 m/sec)	-	-	0.04		1.2°	- 8.8°
	2. Plaster	0.02	2100	0.015		0.5°	- 8.3°
	3. Brick	0.60	1800	0.760		23.6°	15.3°
	4. Plaster	0.02	1900	0.023		0.7°	16.0°
	5. Inside surface (still air)	-	-	0.13		4.0°	
	Total wall	0.64		0.968	1.03	Δt: 30°C	
BASEMENT UNINHABITABLE	1. Underground	-	-	0.14		3.4°	- 6.6°
	2. Plaster	0.02	2100	0.015		0.4°	- 6.2°
	3. Brick	0.73	1800	0.924		22.5°	16.3°
	4. Plaster	0.02	1900	0.023		0.6°	16.9°
	5. Inside surface (still air)	-	-	0.13		3.1°	
	Total wall	0.77		1.232	0.81	Δt: 30°C	

For each existing wall type the calculated interface temperatures (in ^{O}C) are also shown in Fig. 47 , assuming a winter design temperature of $-10^{O}C$. This corresponds closely to the average daily minimum outdoor air temperature for the coldest month - January 1963 - in Berlin-Dahlem.

Jan	Feb	Mar	Apr	May	Jun
- 3.2	- 2.0	0.1	3.9	8.4	11.6
(-11.0 1963)	(-12.3 1956)	(- 7.7 1962)	(- 3.8 1973)	(0.2 1962)	(4.1 1962)

Jul	Aug	Sep	Oct	Nov	Dec
13.0	12.6	9.5	5.8	2.1	- 1.0
(5.1 1979)	(5.8 1956)	(2.7 1952)	(- 1.2 1974)	(- 4.8 1952)	(- 6.5 1969)

Fig. 47

Average daily minimum temperatures for Berlin-Dahlem in ^{O}C; values in brackets show average daily minimum temperatures for the coldest month during the observation period 1947-1977 [22],[27]

Economy of operation of the building requires that the heat exchange with the outside should be kept to a minimum. The poor thermal performance of the solid brick-walls can be reduced by the addition of insulation. Economical thickness of insulation will be reached when it will cost more to add further insulation than will be saved in the over-all heating and operating costs. More information about optimizing insulation can be obtained from several publications. [38],[39]

Placing the insulation on the inside or outside of the brick-wall doesn't make any difference to the over-all heat flow through the wall. But various problems can be avoided by placing the insulation outside the brick-wall: thermally induced stresses and movements could be greatly reduced, thermal bridging problems could be minimized and condensation might not occur.

In terms of historically preserved walls facing the streed, additional insulation has to be placed inside. Without carefully looking at water vapor flow through the wall this may create serious condensation problems accompanied with reductions in indoor comfort levels.

Condensation Problems and Possible Improvements

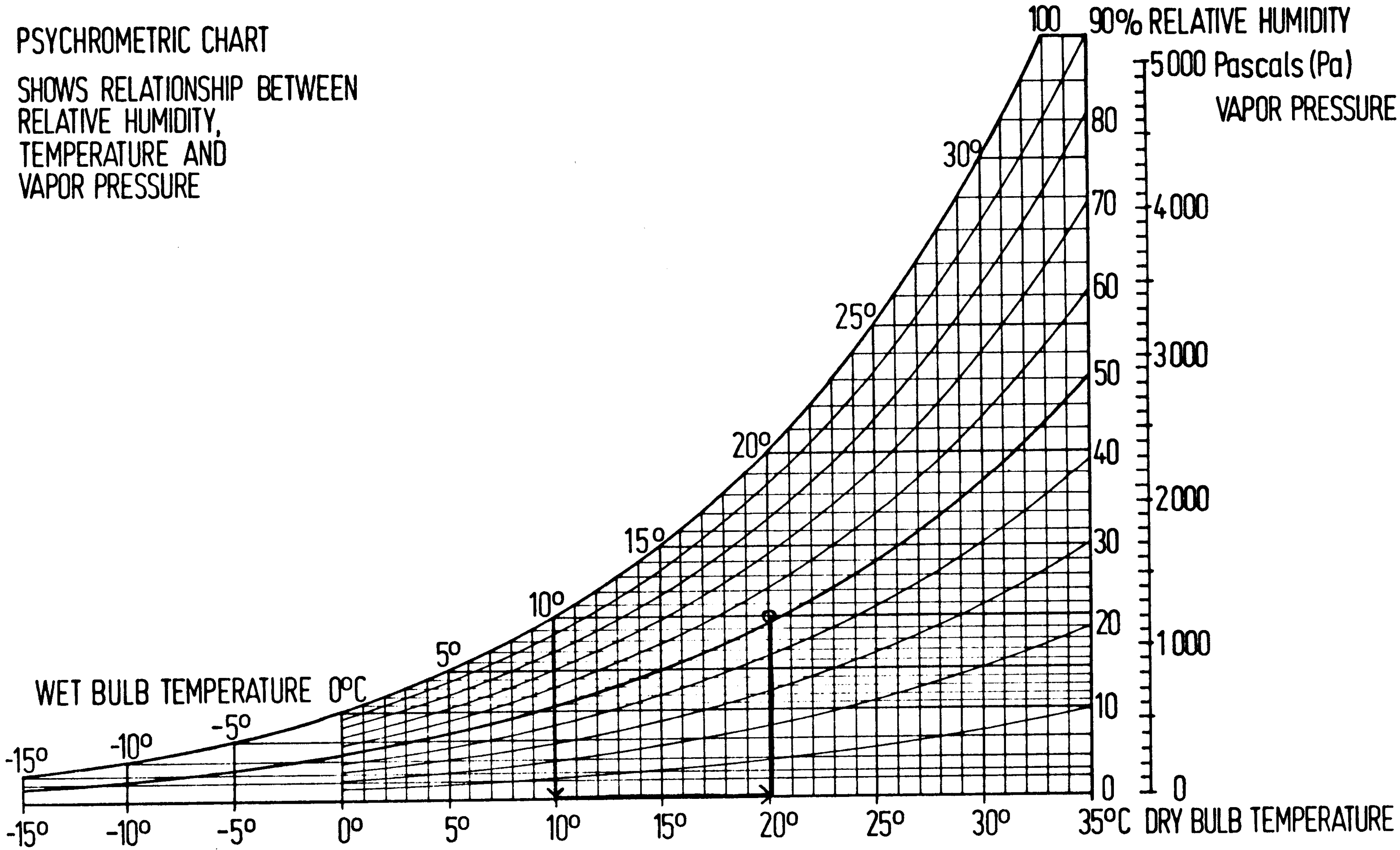
The control of moisture due to condensation either on the wall surface or within the wall depends on an understanding of the mechanics of condensation. Atmospheric air is a mixture of dry air and water vapor. At a given temperature air is saturated when the space occupied by the mixture holds the maximum possible weight of water vapor at that temperature. The amount of water vapor necessary to saturate the air at constant pressure depends upon the temperature of the air -the higher the temperature the more water will be required. [40]

The water vapor in air is called humidity, and relative humidity (R.H.) is the ratio of the amount of water vapor which a mixture contains to the amount required for saturation at a given temperature. For a fixed amount of water vapor in the air, the relative humidity will vary with the temperature: increasing as the temperature is lowered, and decreasing as the temperature is raised.

A convenient way to follow the changes that take place in these inter-related phenomena is by means of a psychrometric chart which is a graphical representation of all possible conditions within the range for which the chart is constructed. One design of such a chart is shown in Fig. 48 .

The horizontal scale is air temperature or dry-bulb temperature and the vertical scale shows the vapor pressure at different moisture content levels. Vertical lines are, therefore, constant temperature lines; horizontal lines are constant moisture content lines. The curved line on the left is the saturation line or 100% relative humidity line, which represents the maximum amount of vapor that can be held at various temperatures and is a boundary of the chart. The temperature at points along this line are referred to as saturation, or dewpoint,temperatures. Other degrees of saturation are shown by the other curved lines for relative humidities of 90%, 80%, etc. [37]

Fig. 48


PSYCHROMETRIC CHART
SHOWS RELATIONSHIP BETWEEN RELATIVE HUMIDITY, TEMPERATURE AND VAPOR PRESSURE
100
90% RELATIVE HUMIDITY
5000 Pascals (Pa)
VAPOR PRESSURE
80
70
4000
60
50
3000
40
2000
30
20
1000
10
0
0
30°
25°
20°
15°
10°
5°
WET BULB TEMPERATURE 0°C
-5°
-10°
-15°
-15°
-10°
-5°
0°
5°
10°
15°
20°
25°
30°
35°C
DRY BULB TEMPERATURE

For instance (Fig. 48) if saturated air (100% R.H.) at a temperature of 10°C is warmed to a temperature of 20°C, the mixture is no longer saturated (only 50% R.H.) but will also absorb additional water vapor. The reserve is, of course, true. If unsaturated air is cooled at constant pressure, a temperature will be reached at which the air is saturated. This temperature is called the "dew point" and if the mixture is cooled below the dew point, water will condense from the air.

It is also important to understand that the total pressure of a given volume of air is the sum of the partial pressure of the air plus the partial pressure of the water vapor; that is, 1m^3 of air at 20°c temperature and 0% R.H. has less pressure than 1 m^3 of air at 20°C and 50% R.H.. If the 2 m^3 of air are connected in any way, a flow will occur from the higher to the lower pressure until a condition of equilibrium occurs. Because of this pressure difference moist air in a building will move to the drier outside air.

Vapor diffusion will also be determined by the length of the flow path and the permeability to water vapor of the particular material.

Condensation occurs as "surface condensation" and as "interstitial condensation". Surface condensation occurs when warm moist air comes into contact with a cold exterior wall whose inner surface temperature is below the dew point temperature. However, as shown in a previous section, there is a temperature gradient across the wall, and if the materials of the wall are such as to allow the flow of moisture vapor, then there may be a point within the element where the temperature is at dew point. In this situation condensation will occur within the fabric: this is known as "interstitial condensation". [19]

Because of the pressure differential which exists between the usually warm moist inside air and the cold dry air, the vapor movement is outward through the interstices in the wall. In this case the inner surface temperature is above the dew point temperature, and the dew point occurs within the wall. When the temperature of the moving moisture-ladened air is lowered to the dew point, condensation occurs.

In order to deal with this problem it is necessary to consider vapor diffusion and rate of vapor flow (G) through the wall:

$$G = \frac{1}{R_V} (P_{vi} - P_{vo})$$

Where R_V = vapor resistance = l/V_p
(l = thickness in m:
l/V_p = vapor resistivity)
P_{vi} = indoor vapor pressure in Pascal
P_{vo} = outdoor vapor pressure in Pascal

Note the similarity with the heat flow equation:

$$\frac{U}{A} = \frac{1}{R} (t_i - t_o)$$

This indicates that vapor pressure gradients can be obtained in the same way as temperature gradients. It was shown in the previous section that the temperature drop through an element was given by:

$$\text{temperature drop} = \frac{R}{\Sigma R} (t_i - t_o)$$

So in a similar manner, the vapor pressure drop through any wall component can be found from the following:

$$\text{vapor pressure drop} = \frac{R_V}{\Sigma R_V} (P_{vi} - P_{vo})$$

The entire calculation procedure is explained by using case 2 (Fig. 52) as an example:
Indoor air temperature is 20°C, indoor relative humidity is 55%; outdoor air temperature is -10°C, outdoor relative humidity in Berlin for December is 88%. Check if and where condensation will appear.

Mean Daily Relative Humidity in Berlin-Dahlem: [27]

Jan	Feb	Mar	Apr	May	Jun
87%	84%	76%	72%	71%	71%
Jul	Aug	Sep	Oct	Nov	Dec
73%	74%	82%	86%	86%	88%

Fig. 49 Comparative values of thermal and vapor resistivity for various building materials [41].

Materials	Thermal resistivity ($m\,K\,W^{-1}$)	Vapour resistivity ($MN\,s\,g^{-1}\,m^{-1}$)
Brickwork	0.69–1.38	25–100
Concrete	0.69	30–100
Rendering	0.83	100
Plaster	2.08	60
Timber	6.93	45–75
Plywood	6.93	1500–6000
Fibre building board	15.2–18.7	15–60
Hardboard	6.93	450–750
Plasterboard	6.24	45–60
Compressed strawboard	9.7–11.8	45–75
Wood-wool slab	3.66	15–40
Expanded polystyrene	27.72	100–600
Foamed urea-formaldehyde	27.72	20–30
Foamed polyurethane (open or closed cell)	27.72	30–1000
Expanded ebonite	27.72	11 000–60 000

Step 1: Calculate total vapor resistance for the given wall using the values provided in Fig. 49 :

0.02m	plaster	x	60MNs/gm =	1.2 MNs/g
0.21m	brick	x	92MNs/gm =	19.2 MNs/g
0.04m	insulat.	x	200MNs/gm =	8.0 MNs/g
0.02m	plaster	x	60MNs/gm =	1.2 MNs/g
0.29m	wall			29.7 MNs/g

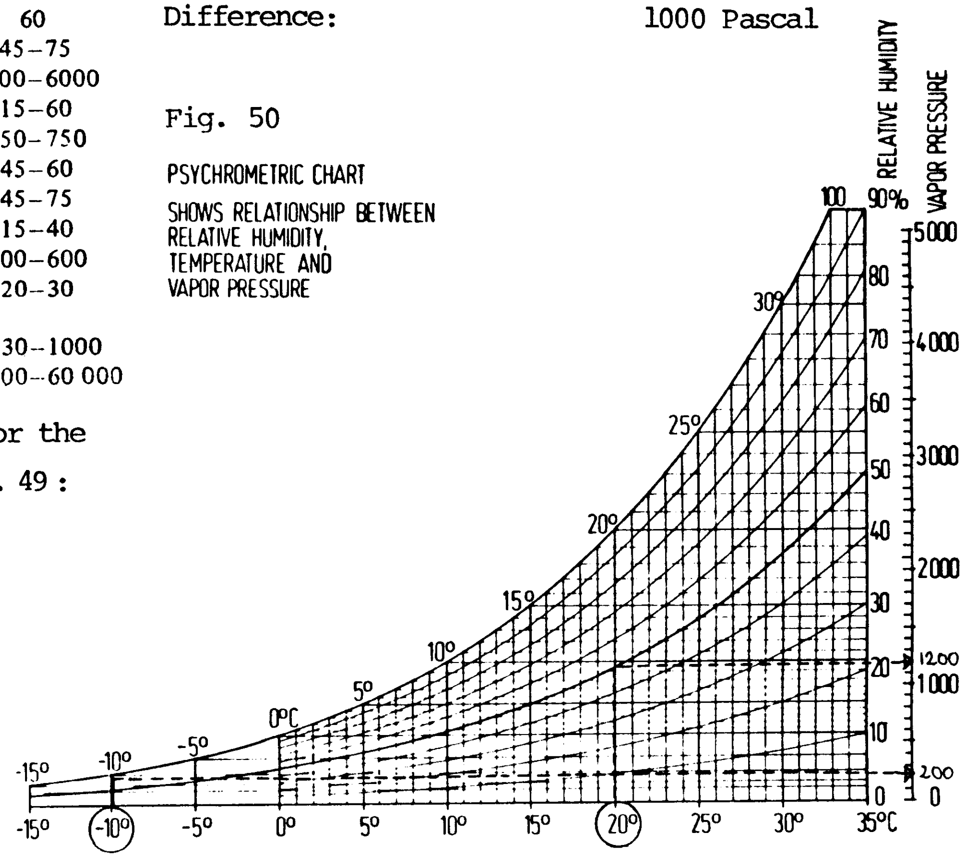
Step 2: Determine vapor pressure difference between actual indoor temperature and actual outdoor temperature using the psychometric chart (Fig. 50):

t_i = 20°C, R.H. = 50% --> 1200 Pascal

t_o = -10°C, R.H. = 88% --> 200 Pascal

Difference: 1000 Pascal

Fig. 50



Step 3: Calculate vapor pressure gradients for the composite wall starting from the inside wall:

$$1200 \text{ Pa} - \frac{1.2 \text{ MNs/g}}{29.7 \text{ MNS/g}} \times 1000 \text{ Pa} = 1160 \text{ Pa}$$

$$1200 \text{ Pa} - \frac{1.2+19.3 \text{ MNs/g}}{29.7 \text{ MNs/g}} \times 1000 \text{ Pa} = 510 \text{ Pa}$$

$$1200 \text{ Pa} - \frac{1.2+19.3+8.0 \text{ MNs/g}}{29.7 \text{ MNs/g}} \times 1000 \text{ Pa} = 240 \text{ Pa}$$

Step 4: Choose the wet bulb temperature (= dew point gradient) according to the calculated vapor pressure gradients using the psychometric chart (Fig. 51)

1200 Pa --- 10.0°C
1160 Pa --- 9.5°C
510 Pa --- -1.0°C
240 Pa --- -10.5°C
200 Pa --- -12.0°C

Step 5: Draw actual temperature gradients from and dew point gradients in one graph using the same temperature scale (Case 2 in Fig. 52).

If the actual temperature falls below the dew point, condensation will take place. This occurs where the broken line (dew point gradient) crosses the continious line (actual temperature gradient). The area enclosed by both lines represents the endangered zone inside the wall where condensation will occur, assuming the given minimum outdoor temperatures.

Fig. 51

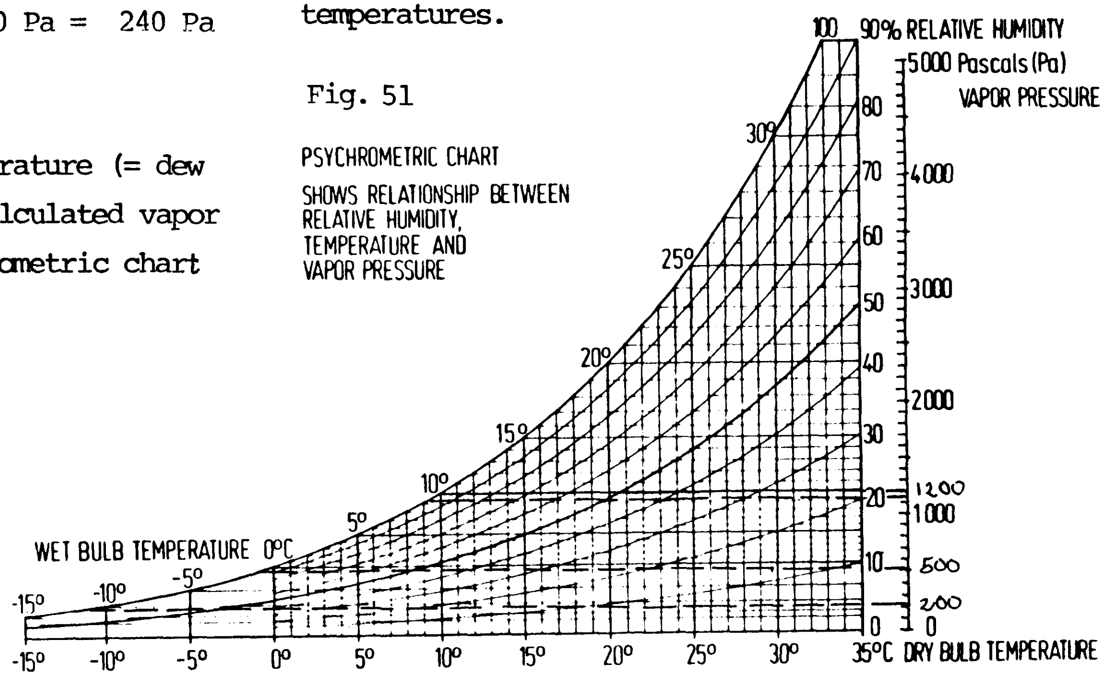
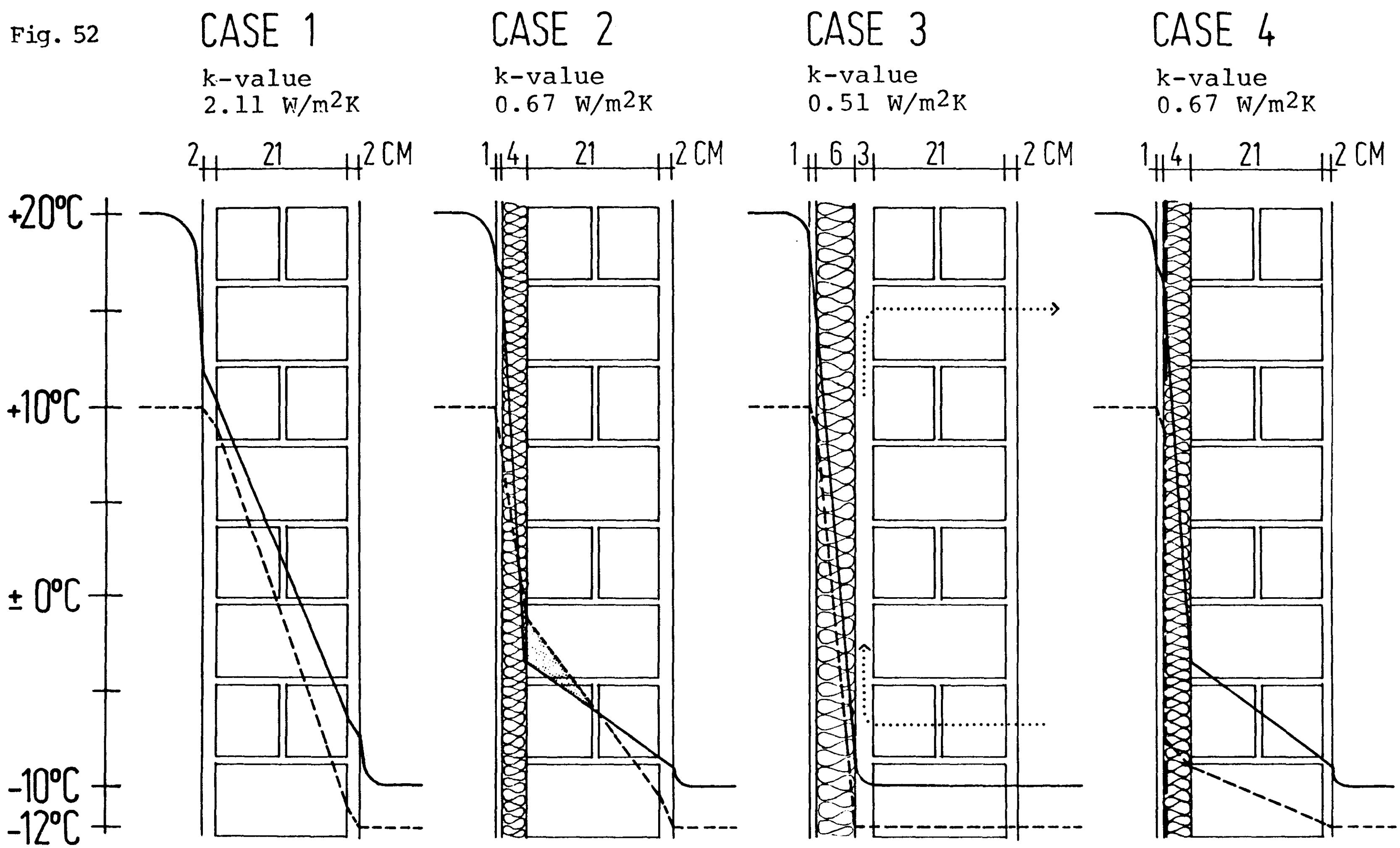


Fig. 52



ACTUAL TEMPERATURE GRADIENT THROUGH THE COMPOSITE WALL

DEW POINT TEMPERATURE GRADIENT THROUGH THE COMPOSITE WALL
(FOR 50% R.H. INDOOR AND 88% R.H. OUTDOOR)

Evaluation of existing and improved wall construction (see Fig.52 on previous page):

Case 1: Existing wall - upper floor.
Condensation will not occur because of the wall's low k-value, which allows the heat to flow very easyly from the inside to the outside and thereby keeps the wall warm and above dew point conditions. In terms of its thermal properties this wall is not sufficient.

Case 2: Interior insulation added - no vapor barrier. The thermal behavior of the wall is improved by adding 4cm of expanded polystyrene. Not so the condensation problem: if a lightweight insulation element is placed on the inside of a wall the result may be interstitial condensation. This will reduce the thermal effectiveness of the wall and can lead to structural damages in the brickwall.

Case 3: Interior insulation with vented airspace. No condensation will occur. But using a vented airspace between the brickwall and the insulation reduces the function of the wall to that of a load-bearing structural element: not all its thermal qualities can be exploited. (Solving the condensation problem by giving up thermal advantages)

Case 4: Interior insulation with vapor barrier. The risk of any condensation is removed by the insertion of a vapor barrier, but it is evident that the vapor barrier would not have any effect if it had been placed on the other side of the insulation, i.e. on the cold face. Hence, vapor barriers should always be placed on the warm side. Without adequate ventilation this can lead to humid, uncomfortable indoor conditions.

It must be noted that all temperature gradient shown in these four examples are for steady-state conditions.

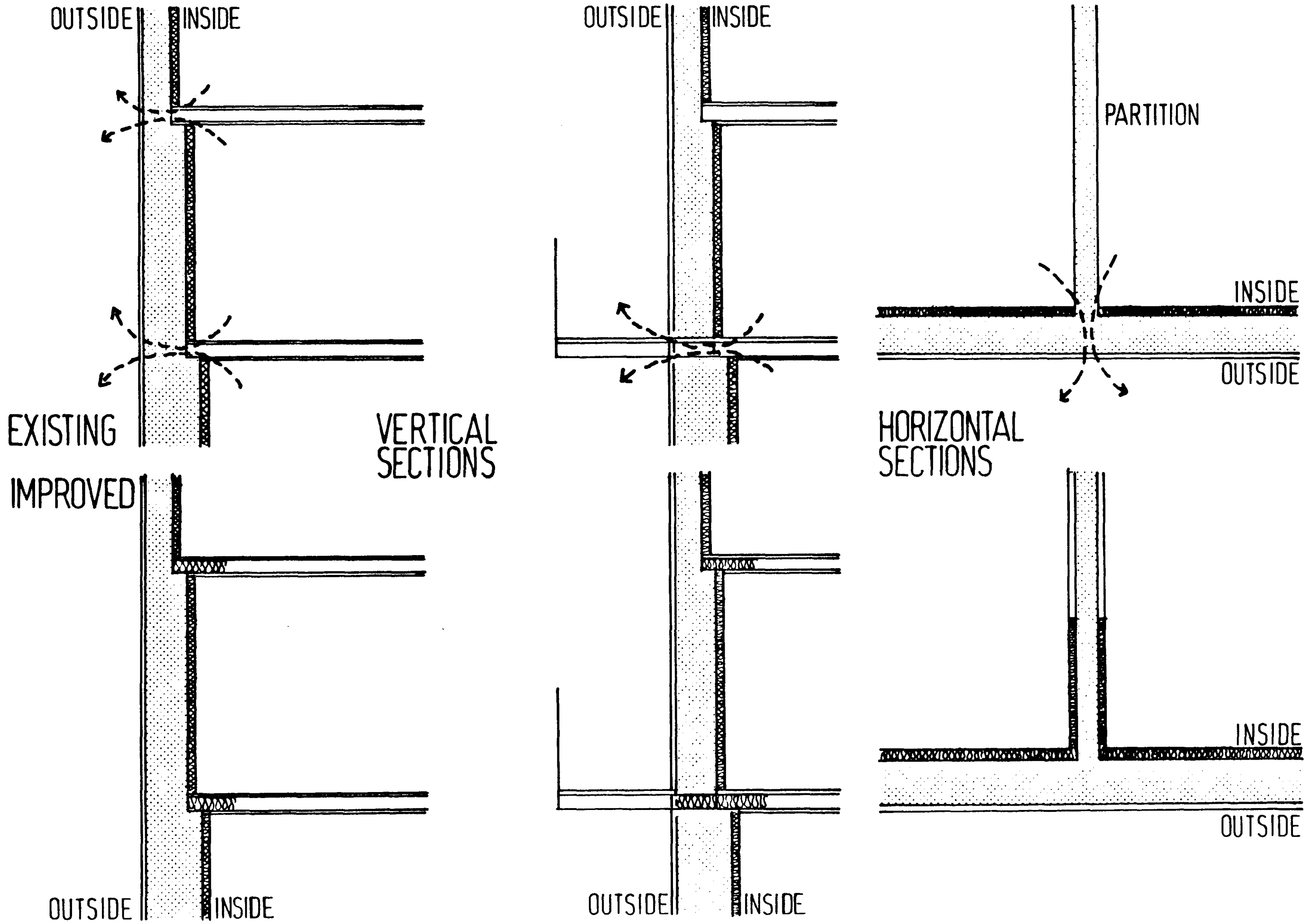
Thermal Bridges in Walls

The previous discussion about the significance of the position of the insulation has been based entirely upon considerations of uniform parallel heat flow paths through the enclosure, although it was intimated that this is not always the case. What happens in situations where all heat flow paths don't have the same thermal resistance? Problems usually arise when there are special paths through the enclosure that have lower resistance (like window- sills) and through which heat flows away more rapidly, producing cold spots on the interior surface. Practical construction cannot always avoid such situations.
Especially after adding interior insulation thermal weakness often occurs at wall-floor or wall-partition intersections. The temperature at these spots is greatly reduced in relation to the rest of the exterior wall and the temperature difference is very large.

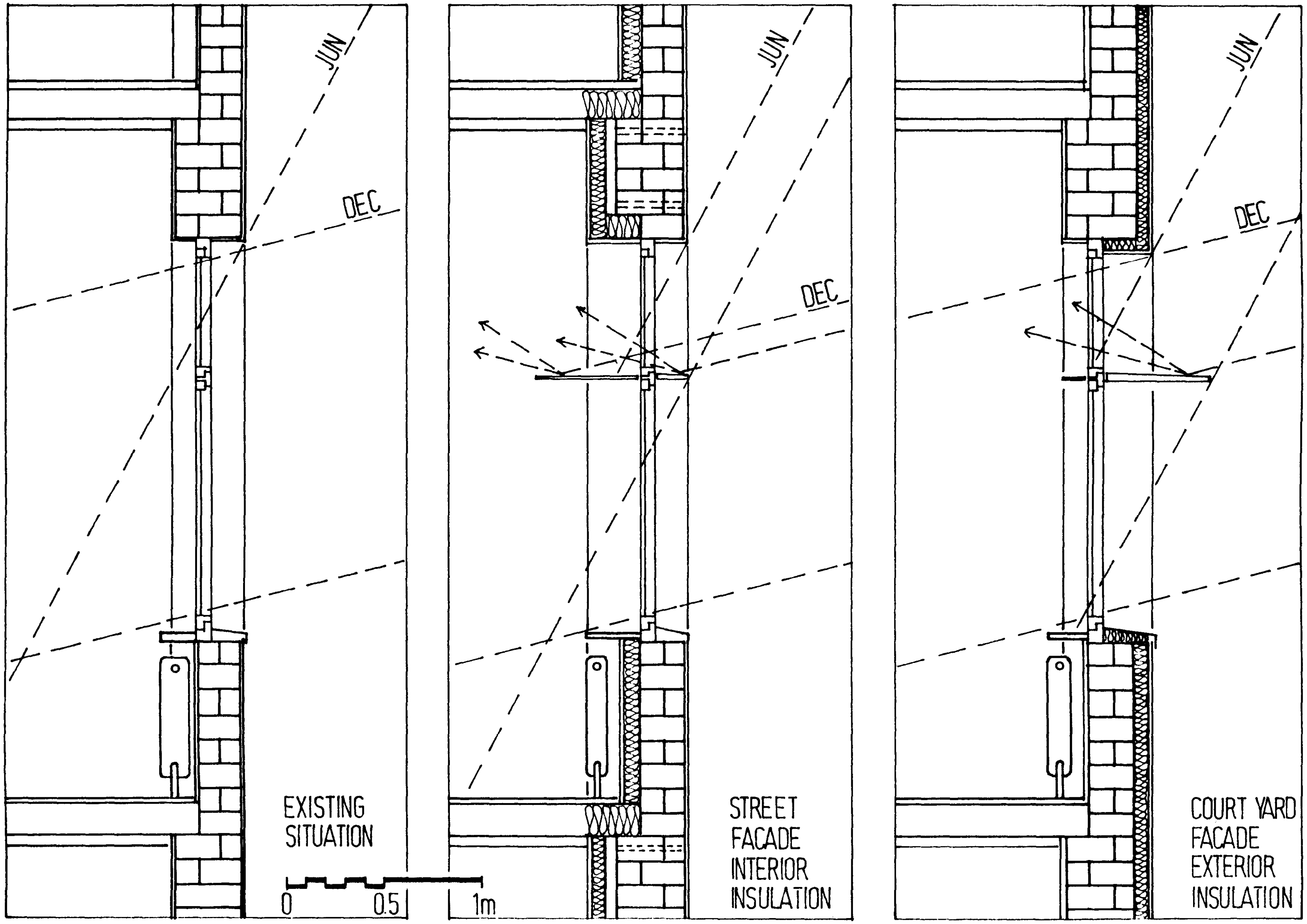
The problem is further aggravated if the floor slab is allowed to project on to the exterior, for example, to form a balcony slab. The fin formed by the projection drains heat from the wall and correspondingly lowers the inside surface temperature - see next page.

The problem might be overcome by insulating both faces of the slab or partition inside the building for a sufficient distance from the wall, until the effect of the heat loss would no longer affect the surface temperature of the exposed surfaces.

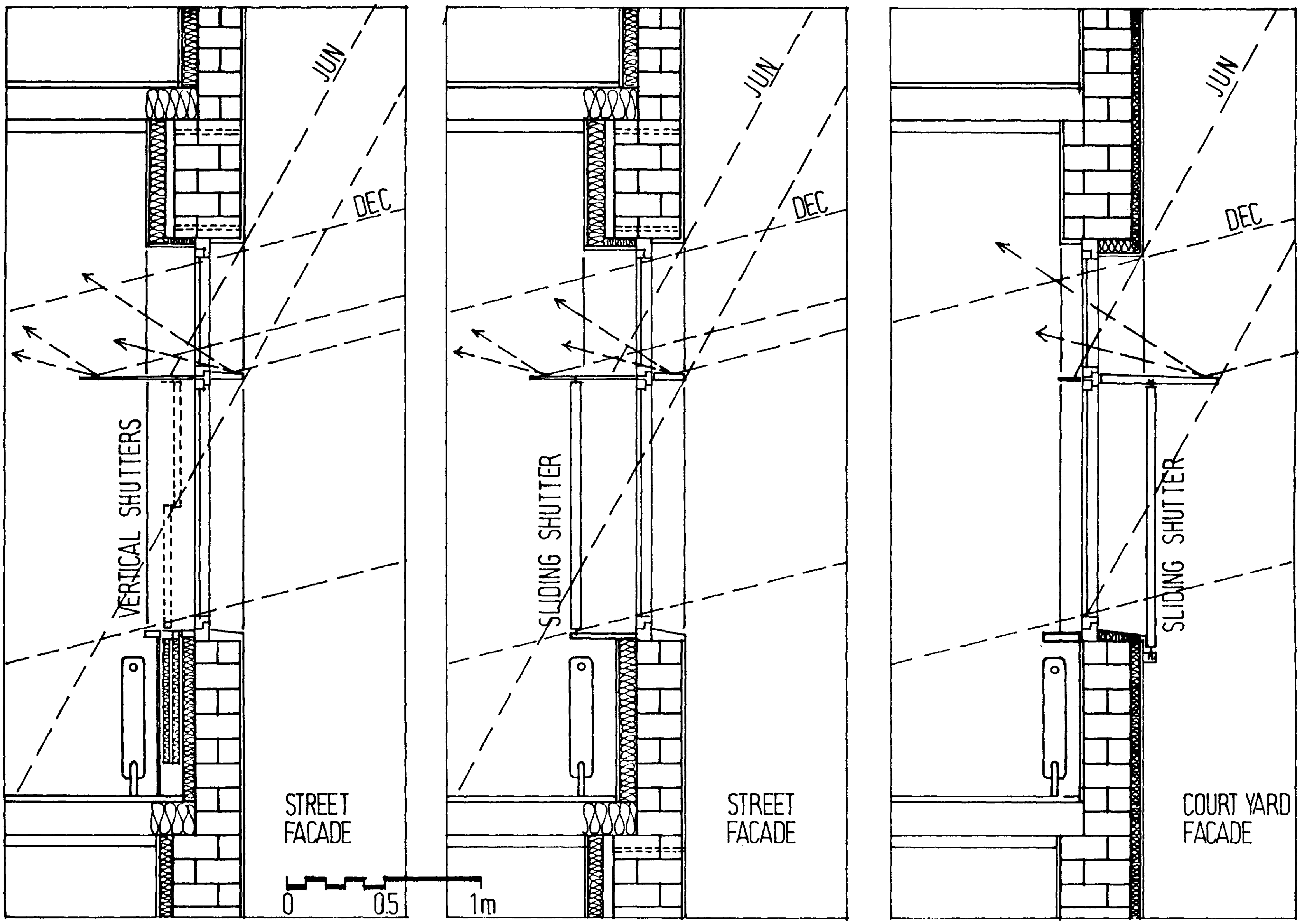
The exterior corner of a building also will experience reduced wall surface temperatures because of both the reduced convection in inside corners and the increased exposed surface on the outside. Possible improvements are shown next page.


OUTSIDE
INSIDE
EXISTING
IMPROVED
OUTSIDE
INSIDE
VERTICAL SECTIONS
OUTSIDE
INSIDE
OUTSIDE
INSIDE
PARTITION
INSIDE
OUTSIDE
HORIZONTAL SECTIONS
INSIDE
OUTSIDE

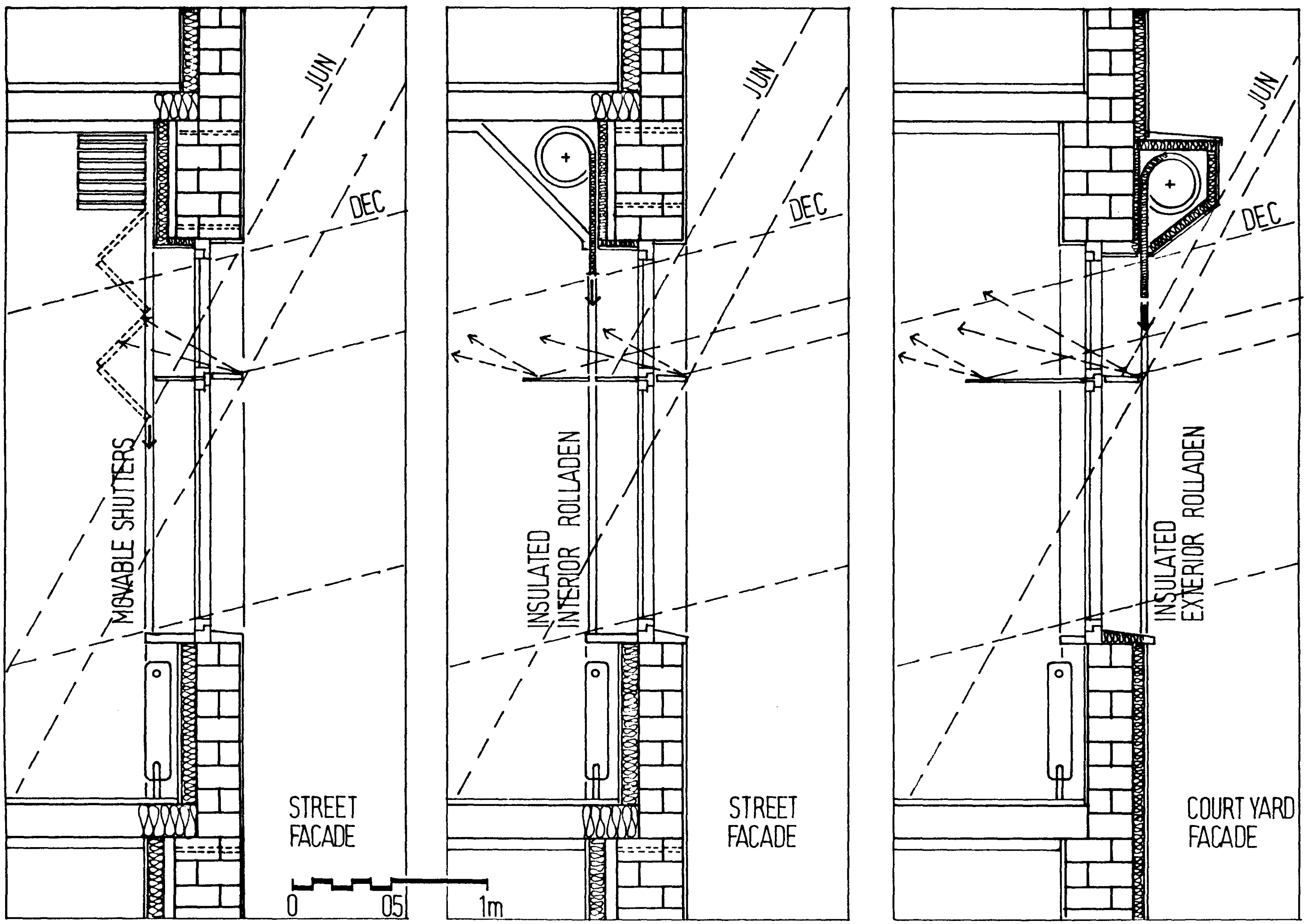
IMPROVEMENTS OF BUILDING SKIN (WITHOUT NIGHT INSULATION)



IMPROVEMENTS OF BUILDING SKIN (WITH NIGHT INSULATION)



IMPROVEMENTS OF BUILDING SKIN (WITH NIGHT INSULATION)



Windows

Designers must recognize the importance of various fenestration materials and their effects on the energy balance of a building. Windows may be considered from several standpoints:

- architectural,
  by identification of design options and their synthesis to achieve energy conscious solutions
- thermal,
  by design for heat losses and gains and surface temperatures consistant with occupant comfort
- accustic,
  by providing reduction of outdoor sounds
- economic,
  by evaluation of first costs and overall life-cycle costs of alternative window designs
- human need,
  by the psychological desire or physical need for windows, and the proper illumination standards which satisfy the projected use of the space and occupant comfort and acceptance.

As part of this thesis the main concerns are thermal considerations in relation to human needs:

How much solar radiation can be admitted inside the building? How much heat can be stored inside during the period of irradiation? How much heat is lost during periods without solar irradiation? Does the interior space stay within comfort levels?

Solar-optical Properties of Glazing Materials

The ability of glazing materials to transmit solar radiation depends on the wavelength of the irradiation, chemical composition and thickness of the glazing material, and the incident angle of solar radiation.

Solar radiation spectrum

Fig. 53 shows the solar spectrum at sea level on a clear day when the sun is directly overhead (= the air mass is 1.0). The invisible ultraviolett portion shorter than 400 nm (= 0.4 μm) in wavelength contains only about 5% of the total solar energy. This small fraction is very important, however, because it is responsible for fading of fabrics, drapes, rugs, upholstery and

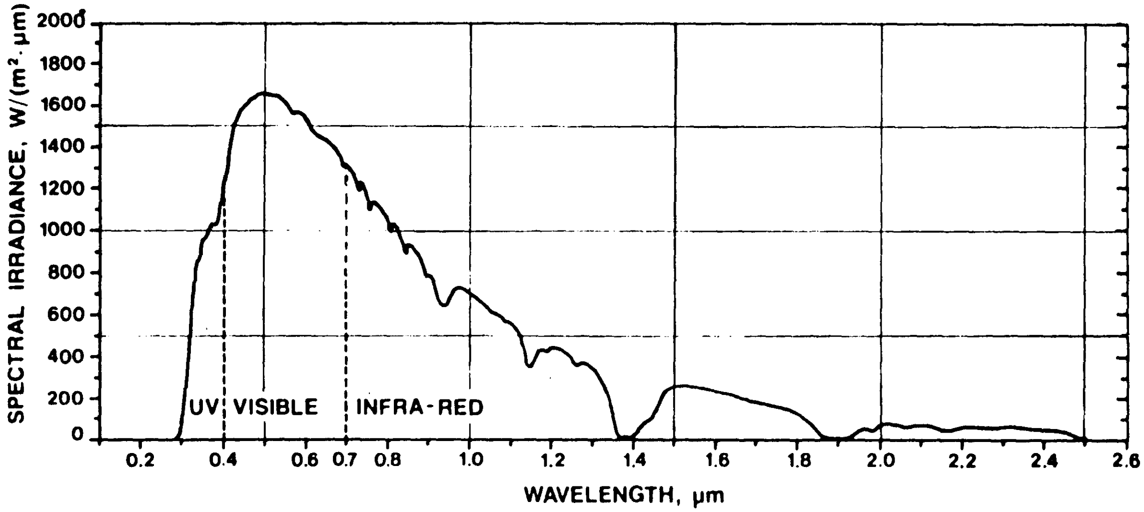


Fig. 53
The solar spectrum at the earth's surface with the sun directly overhead at sea level (air mass = 1.0)

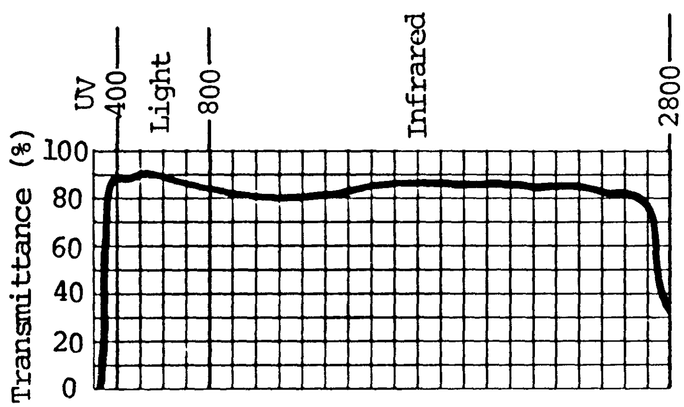
deterioriation of paints unless some kind of protection is provided.

Only the range between 400 to 700 nm (0.4 to 0.7µm) is visible, and therefore properly termed "light" or "sunlight". It accounts for about 47% of the total solar energy that reaches the earth.

The near-infrared portion of the spectrum, between 700 and 3000 nm (0.7 to 3.0µm), contains the remaining 48% of the terrestrial solar irradiation. This is quite invisible to the human eye, although it can be detected readily by electronic or thermal means. [42]

Transmittance of solar radiation:
Most clear glass transmits nothing below a wavelength of 300 nm. About 50% of the UV-radiation is transmitted for incident angles up to 30 degree. Transmittance in the visible range is quite high, as is transmittance in the near infrared, out to the end of the solar spectrum at 2000 - 3000 nm. At that point, for thickness of 3 nm and above, transmittance falls abruptly to virtually zero and none of the longer infrared waves is transmitted (Fig. 54).

Fig. 54 Transmittance of solar radiation for clear glass (2.8mm thick)



Greenhouse-effect:
Radiation above this wavelength is entirely absorbed by ordinary glass and this seems to be the reason for the so-called "Greenhouse-effect", by which solar radiation is trapped when it enters an enclosed space through a glass window. The incoming short-wave radiation is absorbed and converted to heat (= long-wave radiation) by surfaces which then become radiation sources. The radiant energy absorbed by the window raises its temperature until the absorbed energy can be dissipated, most of it to the colder outdoor environment, but some of it to the inside. This part is not large enough to create the wellknown Greenhouse effect: the principal advantage of glass as a building material lies in its ability to minimize convection heat losses. (One can demonstrate this by making an enclosure of polyethylen, known to be quite transparent to long-wave radiation: this enclosure will warm up just like a glass enclosure.)

Improving Glazing Systems

Staring with the relatively high k-value of single glazing (6.0 W/m^2K) some techniques for reducing the overall heat transfer rate have been observed or proposed during the years. These include screens and other external factors which reduce radiative and forced convective heat transfer, solar control films, transparent heat mirror films, or glass coatings which reduce interior surface emissivity, and a large selection of shades, drapes, blinds and other shutters which will reduce window thermal losses.

Double glazing:

The improvement in performance of double glazed windows is due to the insulating effect of an enclosed air layer. Neglecting frame effects, the nominal k-value of a double glazed window with 12 mm air gap is 3.0 W/m^2K, or 50% less than the k-value of single glazing. In a double glazing window under typical winter conditions, approximately 60% of the heat transfer is due to radiation, with the remaining 40% from convection.

Double glazing with gas-filling:

A number of commonly available gases (CO_2, Argon, SO_2, SF_6, CCL_2F_2, Kr) have properties which reduce convective heat transfer if used as a fill gas between two layers of glas. One must note that the replacement of air with other gases to reduce convective losses results in only a modest reduction of convective heat transfer.

Selective Transmitters

All the previous approaches to reduce heat transfer rates through glass were based on reducing convective losses. Significant reductions in heat transfer rates will be achieved only when radiative losses are reduced.

One approach to reduce the radiative component of thermal losses while maintaining high solar transmission involves the use of thin, transparent optical films which are reflective to the long-wave infrared radiation emitted by room temperature surfaces. These low emittance films known as "Heat Mirrors" can be applied to glass as well as to plastic glazing materials. Building designers

Fig. 55
German double-glazing types:
(12mm airspace)

	Thickness	Daylight-transmission	Total solar-transmission	Shadow-coefficient (normal incidence)	k-value with air-filling	gas-filling
	mm	%	%		W/m^2K	
Normal glass	6-6	80	77	.82	3.0	2.8
Infrastop Auresin	4-4	66	44	.50	1.8	1.4
Infrastop Silber	4-4	48	48	.55	1.8	1.5
Eliotherm azur	6-6	63	44	.50	-	1.3
Eliotherm neutral	6-6	50	41	.47	-	1.5
Intertherm Plus 1.6	4-4	65	65	.75	-	1.9
Intertherm Plus 1.4	4-4	60	56	.64	-	1.7
Climaplus GLS 1.6	6-6	65			1.9	-
Climaplus GLS 1.4	4-4	60			1.6	-
Climaplus GL 324	4-4	74			-	1.9
Climaplus GL 328	4-4	74			-	1.7
Thermoplus 1.6	4-4	65	65	.75	-	1.9
Thermoplus 1.4	4-4	60	57	.66	-	1.6
Airco "SIV"	4-4		65		1.6	-

already specify heat mirror products in the form of some types of reflective glass (see Fig. 55 German glazing types), commercially available products which in addition to reducing solar gain, also reduces winter thermal losses by varying amounts. However, since these products were developed to provide sun control functions, their solar transmittance (25% -50%) makes them generally unsuitable for applications in which winter solar gain and daylight is desirable. [43]
This fall the Italian glass manufacturer S.I.V. will introduce to the German market a new selective coated glass type with remarkable properties: The over-all normal solar transmission of the double glazed unit will be 0.65 with a k-value of 1.6 W/m^2K. The addition of special gas filling would reduce the k-value to 1.4 W/m^2K - a possible further development.
With the large increase in solar gain to thermal loss ratio offered by these materials, solar heating on cloudy days becomes practical for the first time. Logically this also leads to the opportunity to use non-south exposures profitably for solar heating for the first time.
This thesis will explore the degree of utilization for this glass type under the limiting climatic conditions of Berlin (low radiation levels in winter).

Angle of Incidence and Transmission-factor

The transmittance values which are reported by glass manufacturers are generally made at "normal" incidence (angle of incidence is perpendicular to the glass plate) using a spectophotometer which can measure the transmittance as it varies with wavelength. Two values are usually given, the first being for "average daylight", which is the transmittance for the visible portion of the spectrum. It is generally higher than the second value, "total solar", which means that it covers the entire solar spectrum.
Solar transmittance as a function of the angle of normal incidence is available from German glass manufacturers for a number of glazing types. A list of double glazing systms with at least 40% total solar transmittance and k-values better than 2.0 W/m^2K is given in Fig. 55 .

Solar heat gain (SHG) is the product of solar radiation available at the surface of a window and the transmission-factor for the fraction of incident radiation which is transmitted through the glass. SHG depends on latitude, orientation and local weather; the transmission-factor is usually a materials property only, representative of the type of window.
Usually for simplified calculations of solar heat gain a single value - normal transmittance - is given. Whenever such a method is applied, the

Fig.56 Weighted monthly average angle of incidence for a vertical southfacing surface at 52°NL and resulting transmission factors for

double glazing (normal transmittance:0.79):

Month	Incidence (direct beam)	Trans.-factor	Incidence (diffuse)	Trans.-factor
Dec	23.56°	0.79	60°	0.70
Jan/Nov	27.57°	0.79	60°	0.70
Feb/Oct	38.20°	0.78	60°	0.70
Mar/Sep	49.10°	0.75	60°	0.70
Apr/Aug	59.36°	0.70	60°	0.70
May/Jul	65.56°	0.64	60°	0.70
Jun	68.56°	0.60	60°	0.70

triple glazing (normal transmittance:0.70):

Month	Incidence (direct beam)	Trans.-factor	Incidence (diffuse)	Trans.-factor
Dec	23.56°	0.70	60°	0.62
Jan/Nov	27.57°	0.70	60°	0.62
Feb/Oct	38.20°	0.69	60°	0.62
Mar/Sep	49.10°	0.67	60°	0.62
Apr/Aug	59.36°	0.62	60°	0.62
May/Jul	65.56°	0.55	60°	0.62
Jun	68.56°	0.50	60°	0.62

normal transmittance should be replaced by average averaged values which take into account the daily and seasonal variations of the sun's angle of incidence, orientation and latitude of the surface in question (Fig. 56).

Thermal Bridges at Windows

Compared with a wall a window itself is already a "thermal bridge". The whole purpose of multiple glazing, selective coatings or special gas fillings instead of single glazing is to reduce the heat flow through the window and raise the surface temperature of the glass exposed to room conditions, both to increase comfort and raise humidity level that can be maintained before condensation can form on it.

Beside this general "weakness" of glass some other facts must be considered: Factory-sealed multiple-glazing units require a spacer at the edges both to set the required distance between the panes of glass and to assist in making the seal. This spacer, which is often metal, acts as a thermal bridge. The method of mounting the glazing unit into the frame, the design of the frame, the method of mounting the frame into the wall will affect its overall thermal performance (see Fig. 57).

Fig. 57 k-value of different glazing systems in relation to their framing material

Glazing system	Wood-frame Plastic-frame	Metal-frame Concrete-frame
Double glazing (12mm airspace)	3.0 W/m^2K	3.5 W/m^2K
Triple-glazing (2x12mm airspace)	1.9 W/m^2K	2.3 W/m^2K
Double glazing (2-4cm airspace)	2.6 W/m^2K	3.0 W/m^2K
Double glazing (4-7cm airspace)	2.3 W/m^2K	2.8 W/m^2K

The given k-values are valid for window areas smaller than 5 m^2 with 25% or less framing or window areas larger than 5 m^2 with 15% or less framing.

Ventilation

The ventilation conditions inside a building are among the primary factors determining human health, comfort and well-being. They have a direct effect on the human body through the physiological effect of air purity and motion, and an indirect effect through their influence on the temperature and humidity of the indoor air and surfaces.
Ventilation serves three distinct functions [44] :

1. to maintain the quality of the air in the building above a certain minimum level by replacing indoor air, grown stale in the process of living and occupancy, by fresh outdoor air.
2. to provide thermal comfort by incresing the heat loss from the body and preventing discomfort due to moist skin.
3. to cool the structure of a building when the indoor temperature is above outdoor temperature.

Minimum ventilation rates

Many countries have established minimum requirements for permanent ventilation given in terms of either air changes per hour or cubic meters/hr.

German building codes show different minimum air-change rates for residential buildings: [45]

DIN 4108, Beiblatt Nov. 1975:	0.8 AC/hr
DIN 4701, Entwurf March 1978:	0.5 AC/hr
VDI- Richtlinie 2088, Ausg. Dec. 1976:	1.0 AC/hr

Minimum rates of fresh outdoor air:
(DIN 1946, Blatt 1)

Outdoor air temperature	Minimum rates for rooms with smoking permission	Minimum rates for rooms without smoking permission
°C	m^3/hr per pers.	m^3/hr per pers.
-20°	8	12
-15°	10	15
-10°	13	20
- 5°	16	24
0°- 26°	20	30
over 26°	15	23

Heat losses through air infiltration

Air infiltration is a significant portion of the heating load of any type of building. The socalled "Air-Change-Method" bases infiltration losses on an estimated number of air changes commonly used. It might vary from 0.5 air-changes per hour in well tightened new buildings to 1.5 and more in old buildings.

In Germany infiltration losses are calculated by the "Crack-length-method" (DIN 4701), since cracks around windows and doors are a major source of air leakage. Three major facts determine the flow rate of air through cracks:

1. the air leakage characteristics of the windward wall, windows and doors
2. the air leakage characteristics of the leeward wall, windows and doors
3. the difference between the windward and leeward wind pressures due to wind, as well as the difference between inside and outside pressure due to thermal forces acting alone or together.

In practice there is sufficient infiltration of air through window cracks to provide the necessary air flow for minimum requirements of ordinary families. Even in the absence of wind an air flow of about 1.7m^3 per hour of air per one meter of crack length can be expected as a result of temperature gradients.

Thermal Mass

Large southfacing window areas installed in multifamily houses with low heat loss rates can transmit so much solar energy that overheating may occur during periods of peak solar irradiation - as on clear days in March or September. The storage and control of heat in a direct gain building is a major problem confronting the designer.

Berlin's tenement housing with their solid masonry walls effectively help to store solar energy during sunny winter days and retain it for use during evening and night hours. Nevertheless any redesign involving enlargement of southfacing window areas has to be sized properly in order to avoid overheating problems.

In the process of storing and releasing heat, the masonry fluctuates in temperature, yet the object of the passive "heating system" is to maintain a relatively constant interior temperature with moderate swings. The thermal properties , location, quantity, distribution and surface color of the participating heat storage materials in a space will determine the indoor temperature fluctuation over the day (see overheating calculations on page 154 ff).

To be effective for heat storage a material should have the following characteristics:

1. It should have a high thermal capacity.For a given thickness, this means the product of density and specific heat should be large.

2. It should have a high thermal conductivity. The deeper portions of the wall cannot participate in the charging and discharging cycle if they are insolated from the room by a layer of low thermal conductivity material.

3. It should have adequate thickness. Thickness is very important since storage material deep under the surface is so isolated from the the room as to be largely ineffective in the daily charging and discharging cycle.

4. It should be directly or indirectly irradiated by the sun. Lightweight materials in the sunlight can only store little heat and thus become quite hot, transferring the absorbed solar radiation to heating the room air by convection, and to heating other room surfaes by infrared radiation. Overheating might occur.

New thermal storage material [26]

"Sol-AR-Tile" is the trade name of a new lightweight thermal storage material, developed in 1977 at MIT with assistance of Architectural Research Corporation, Livonia, MI, used as ceiling-tiles or floor-tiles.The polymer concrete tiles,two feet square and one inch thick, filled with modified Glauber's salt, absorb the incoming solar energy by changing the phase of the salt from solid to liquid. This phase change takes place at a temperature near the melting point of the salt core (22.8°C) which keeps the storage surface from getting hot and thus the room cannot overheat. During the night the tile becomes a radiant heater that liberates heat at a constant temperature of 22.8°C.The heat capacity of a 1"-tile is 22.5 Btu/sf°F - about four times the heat capacity of 3" of brick. Especially in added greenhouses with large areas of south-glazing and small areas of storage areas, overheating is a normal problem which can be solved by using these tiles.

The greater the thermal capacity of a material, the better the material is for storing heat. If two materials have similar thermal capacity, the material with the higher conductivity is a better storage medium.

The "diurnal heat capacity" of a material surface is the daily amount of heat, per unit of surface area, that is stored and then given back per unit of temperature swing [46].

Fig. 58

Material properties		Concrete	Limestone/Rock	Brick	Pine Wood	Dry Sand	Adobe	Gypsum Board	Water	Sheet Rock
Density	(lb/ft^3)	143	153	112	31	95	120	50	62.4	50
Specific heat	(Btu/lb°F)	0.21	0.22	0.22	0.67	0.19	0.20	0.26	**1.0**	0.20
Heat capacity	(Btu/ft^3°F)	30.0	33.7	24.6	20.8	18.0	24.0	13.0	62.4	10.0
Thermal conductivity	(Btu/ft°Fhr)	1.00	0.54	0.40	0.10	0.19	0.33	0.09	-	0.09
Radiantly coupled mass		Diurnal heat capacity (Btu/ft^2°F)								
Thickness in inches:	1"	2.50	2.80	2.05	1.71	1.50	2.00	0.84	5.19	0.84
	2"	4.99	5.52	4.04	2.96	2.90	3.92	1.60	10.4	1.64
	3"	7.37	7.81	5.73	3.14	3.86	5.44	2.04	15.6	2.04
	4"	9.47	9.17	6.74	2.93	4.14	6.20	2.11	20.8	2.11
	6"	11.9	9.30	6.86	2.76	3.82	6.05	1.92	31.1	1.92
	8"	12.1	8.63	6.36	2.77	3.62	5.62	1.84	41.7	1.80
	12"	11.0	8.29	6.10	2.77	3.61	5.49	1.85	62.4	1.80
	16"	10.6	8.33	6.13	2.77	3.62	5.52	1.85	83.3	1.80

Distribution of Sun Light in a Direct Gain Space

To exploit as much as possible the existing storage capacity in Berlin's tenement housing, the incoming radiation has to be spread over all massive storage surfaces. Different means are available to diffuse and to redirect the direct sunlight: light shelves, louvers, blinds, fins. The colr of the storage surfaces might help to reflect the sun in a diffuse pattern to other regions of the room which are thereby illuminated and heated. Even if the absorption of light-colored surfaces is rather low - compared with the high absorption of dark-colored surfaces - the multiple reflections of various participating surfaces let the light bounce around the room and there diffuse it evenly over the storage surfaces. Only the first 10 cm of the mass of a brickwall are usable for effective thermal storage. The material deep under the surface is so isolated from the room as to be largely ineffective in the daily charging and discharging cycle. Furthermore, there is a time delay associated with conduction through the material so that heat making a round-trip several inches into the material may reappear at the surface 24 hours later when the wall is again charging. Beyond a depth where this is out-of-phase effect begins to happen, added material or too much existing material actually decreases performance.

In a light colored room an absorption degree of 90% can be obtained. Thus, the entire space - walls, floor and ceiling - becomes the thermal storage mass. Calculations for the tenement housing show that the surface area exposed to the sunlight must be 8 - 12 times higher than the southglass area in order to absorb most of the incoming solar energy during the month of March (a month normally associated with overheating problems). Under these limitations temperature fluctuations will stay in a comfortable range throughout a 24 hour period.

CHAPTER 6

CASE STUDY - REDESIGN

Fig.59 Aerial view showing tenement housing in Berlin-Kreuzberg

Passive Solar Retrofit in an Urban Context

A set of desirable goals is confronted with a set of limitations:

Goals	Limitations
Solar gain	Local climatic conditions
Solar access	Site of existing building, surrounding buildings
South orientation	Constraints of given site
Historical preservation	Building codes, preservation-laws
Preservation of street-image and city-image	City-regulations

Despite these limitations the conversion of existing buildings into passive solar ones is actually quite feasible with certain types of buildings that happen to be properly sited and south-oriented.

Existing Building Configuration versus Solar Usage

The most frequent sort of passive solar retrofit (in the USA) is a solar greenhouse that can be attached to the south side of a building without replacing existing walls. Placing some vents in the wall and adding a small fan allows the captured heat to circulate through the adjacent living rooms. the spacial constraints of an urban environment reduce to some extent the application of this type of solar retrofit. Conflicts with streetline requirements generally don't allow the addition of wintergardens, bay-windows or glass-covered balconies. Backfacades are more suitable for these changes. In any event, a building has to meet four important requirements before being considered as a possibility for passive solar retrofit:

- the facade in question should be directly oriented to the south (+30° to -30°, unless louvers are used, then ± 5°)
- enough space should be available to build the added sun space
- enough sun should reach the sun space throughout the year as well as during the day
- enough mass should be available for thermal storage of solar heat

If there isn't enough space available to add sun spaces another type of massive solar retrofit is also feasible in many cases: A Trombe-wall can be created by adding glazing just outside a south-facing masonry wall. If such measures don't require substantial structural changes a simple and cost effective passive solar system can be implemented. [47]

Moreover, the system offers a two season benefit: In winter it acts as a direct thermo-siphon mass wall heat storage system and in summer the same mass wall is converted to create the motive force for stack effect cooling, which utilzes night air ventilation for cooldown of the building's internal mass (See Stephen Hale's Symphony Road Project in Boston).
If structural changes are possible the enlargement of existing windows offers an improvement, too.
Another type of passive solar retrofit involves only the upper part of a building: the roof.
Partly or totally transparent rooftops allow easy access to the sun all year long by retaining the original shape of the roof. Tilted surfaces enlarge the amount of collected solar radiation - see Appendix C . As with active collector-systems for domestic hot water, the problems of storage and distribution of gained heat have to be solved properly.
In addition to valuable soalr heat gains, these spaces can also serve as a positive environmental gain for the tenants of an apartment complex: community space, recreation, plant growth.
If the roof areas are not used for residential purposes the southern roof areas should be utilized to generate domestic hot water by installing active collector systems. In some of Berlin's older tenement-housings the architects of the original design already took advantage of the glass-covered rooftops: they covered north-facing roof areas to create sudios for artists -see Fig. 60. [33]

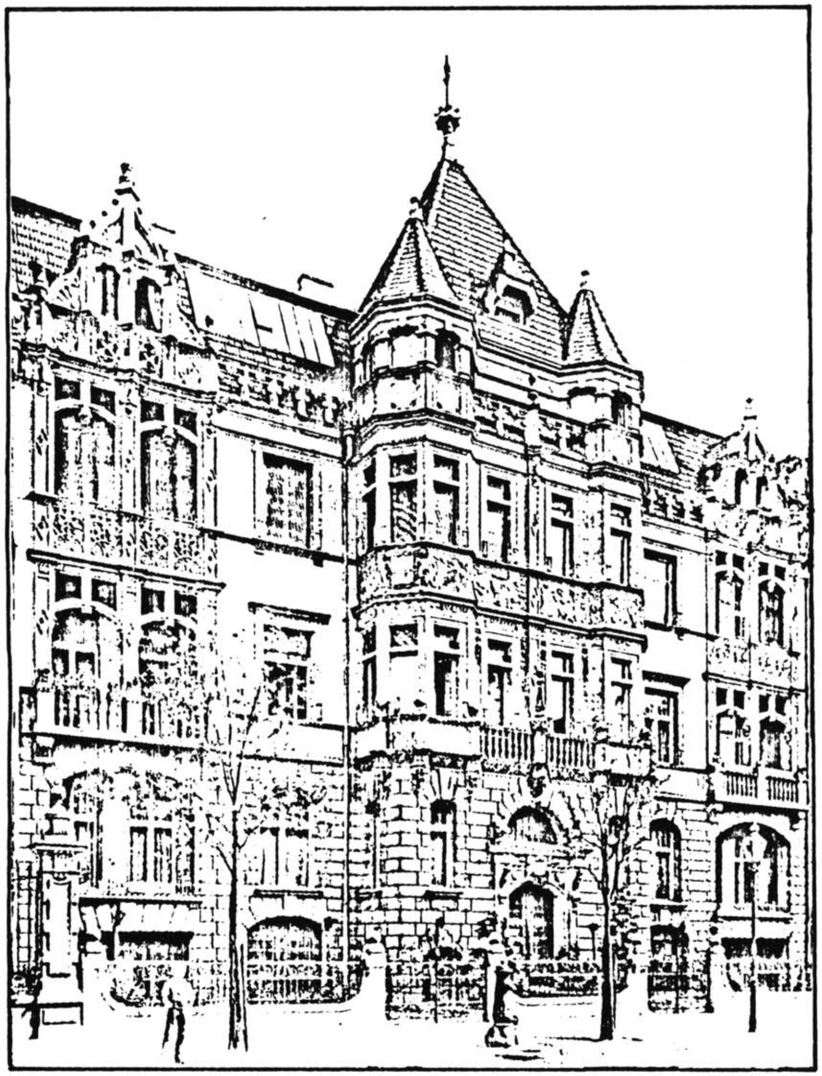
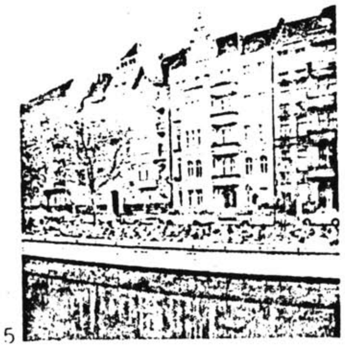


Fig. 60 Streetfacade of a tenament house in Berlin built in 1897, destroyed during World War II

Historical Preservation versus Urban Solar

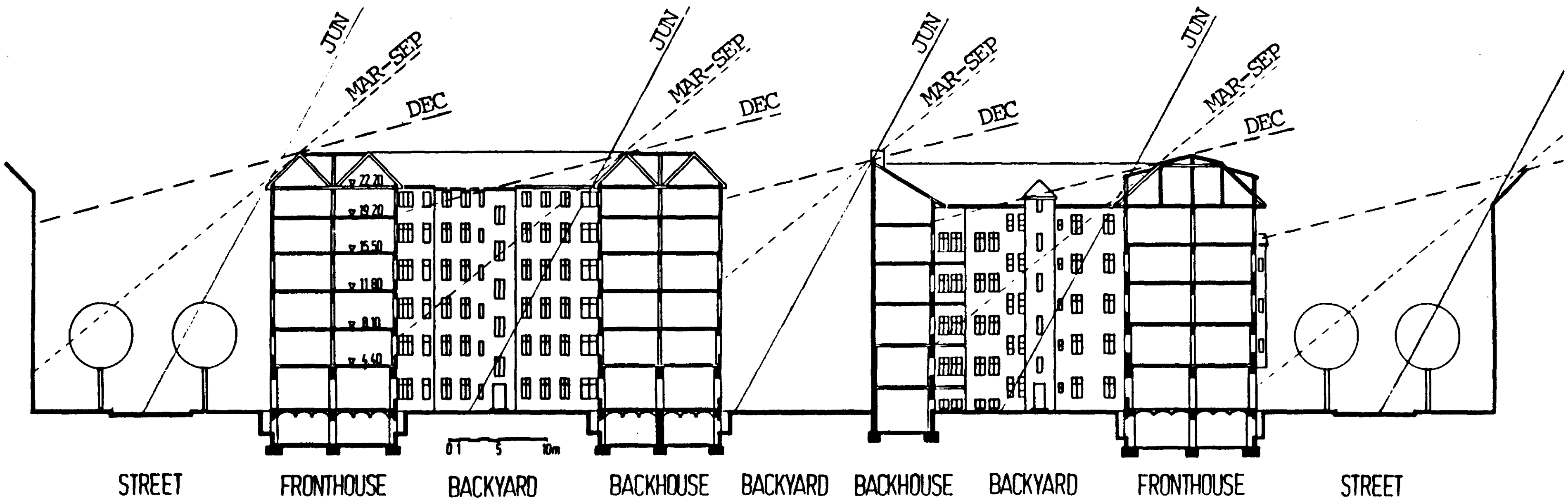
Historical preservation measures and regulations - especially in Berlin - may add another constraint to the addition of solar systems (passive or active). In case of a large number of older tenement houses from the late 19^{th} century, general design regulations for street-facades (Fig. 43) as well as neighboring rights widely restrict remodeling of street lining facades. Any change to the facade design - even new painting - is considered as possible distraction to the overall street character and thus is subject to minute regulations. Adding new elements (like shading devices) to the facade or changing window-size and window partitioning meets a whole set of objections in the name of public intrests.
Thus passive solar retrofit must more or less keep with the existing street-facade and only can add to its character in very discrete modes. In this sense, retrofit is mostly restricted to improvementsof the window area itself (light shelf, louvers, new glazing, night insulation, etc).

5



Backyard-buildings versus Urban Solar

Backyard facades allow a wider option, as their re-design is only subject to building security and formal agreement of affected neighbors, which in turn is negotiable on an informal basis. Changes in the building configuration seem to be quite possible, too. During the 60's building sanitation led to a range of demolitions eliminating back-yard-buildings and clearing out entire courtyards. With more environmental consciousness and increasing opposition from the inhabitants of the old tenement-houses, official building policy in Berlin switched to more careful considerations in changing the existing structures. A house-by-house approach was adopted in order to meet the wishes and expectations of the inhabitants and owners. Backyard buildings might be partly torn down in order to gain better solar access - see next page. Setbacks can be created which form a transition from the higher fronthouses along the streets to the lower backhouses and thereby wide open the densely built-up courtyard situation. Creating inhabitable sun-decks may substitute for lost floor area and high coverage at ground.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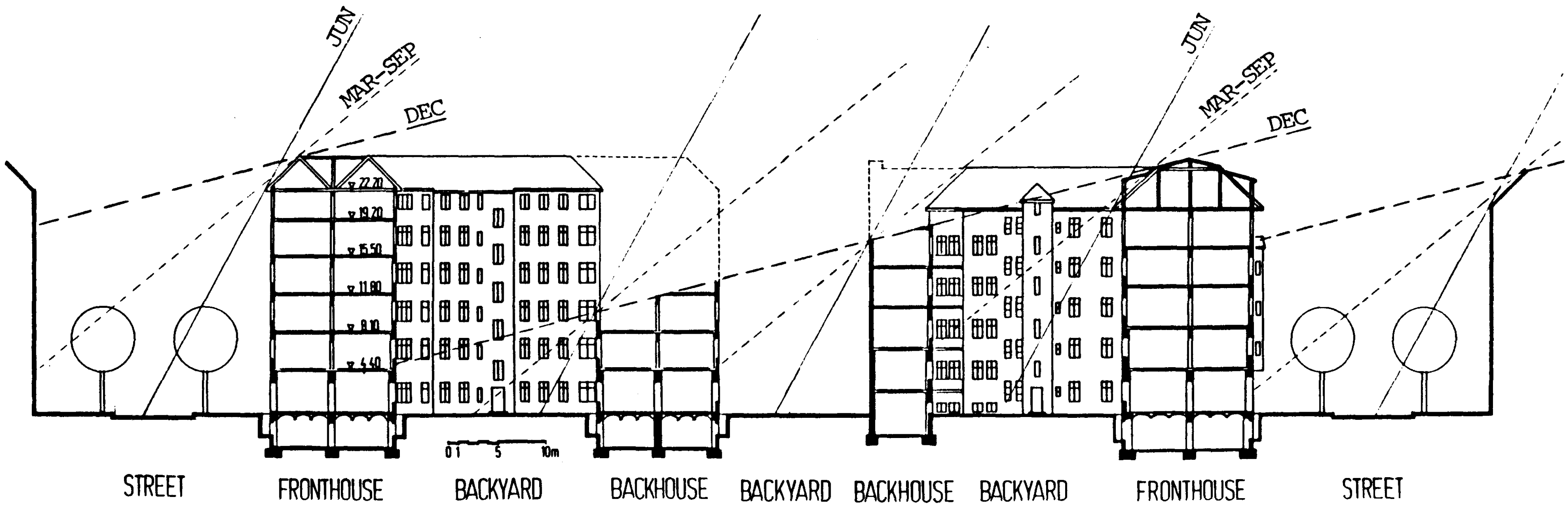
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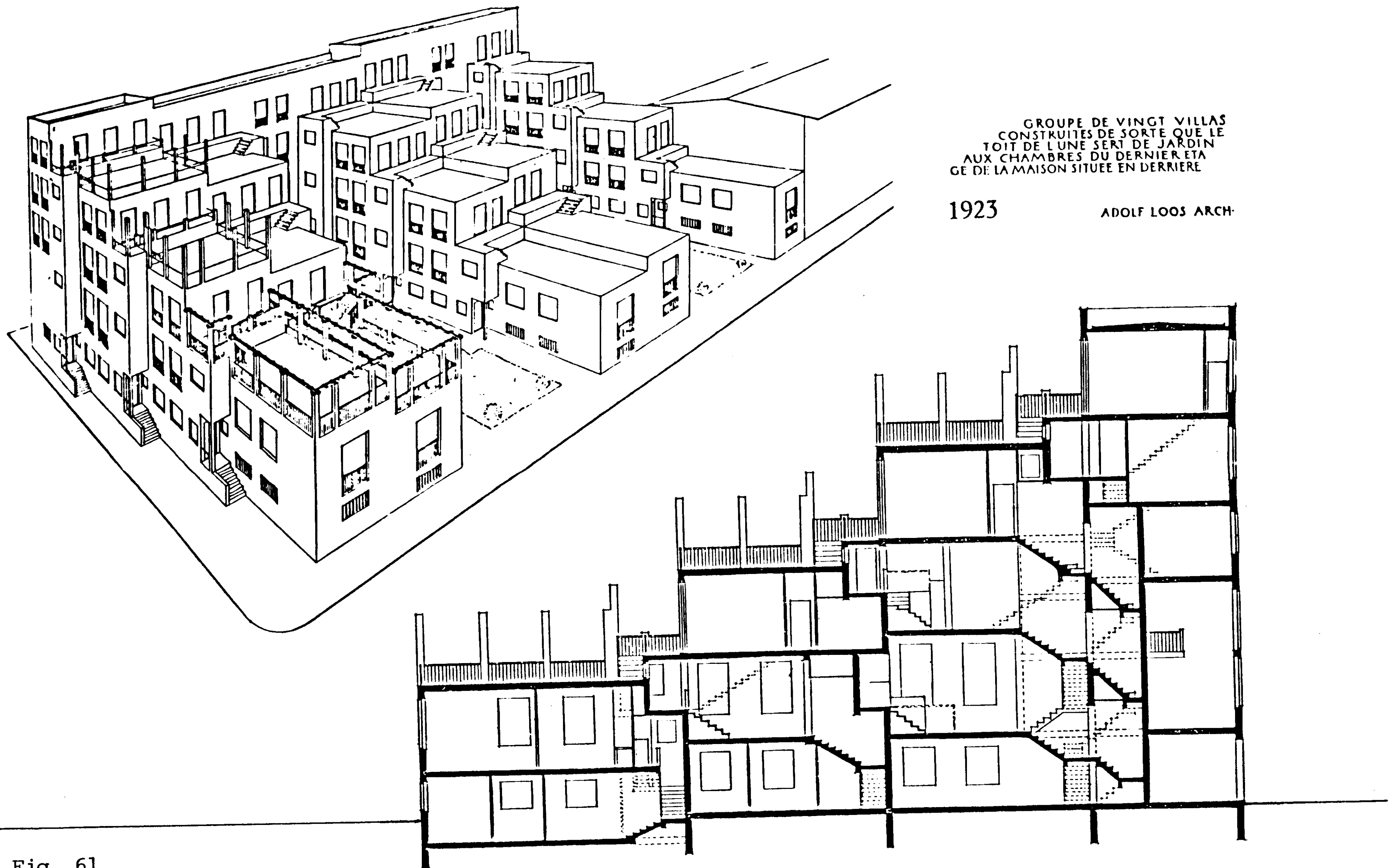

GROUPE DE VINGT VILLAS
CONSTRUITES DE SORTE QUE LE
TOIT DE L'UNE SERT DE JARDIN
AUX CHAMBRES DU DERNIER ETA
GE DE LA MAISON SITUEE EN DERRIERE
1923
ADOLF LOOS ARCH·

Fig. 61

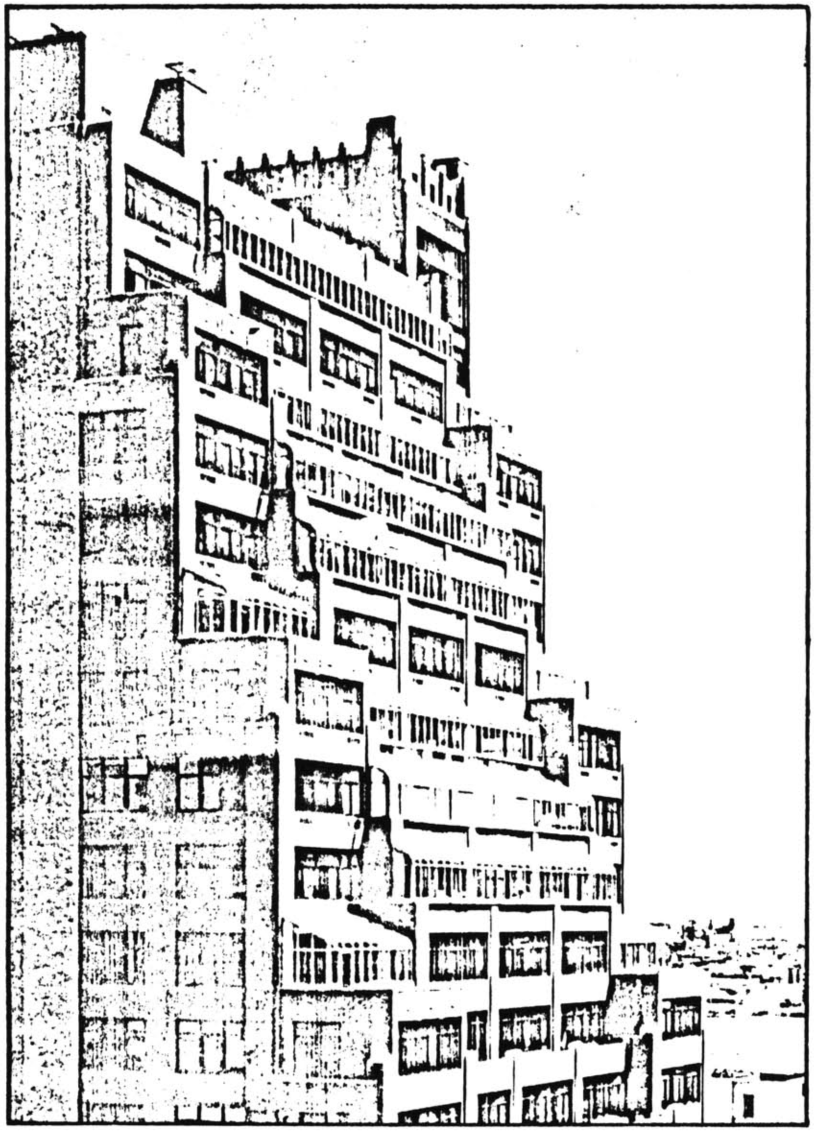
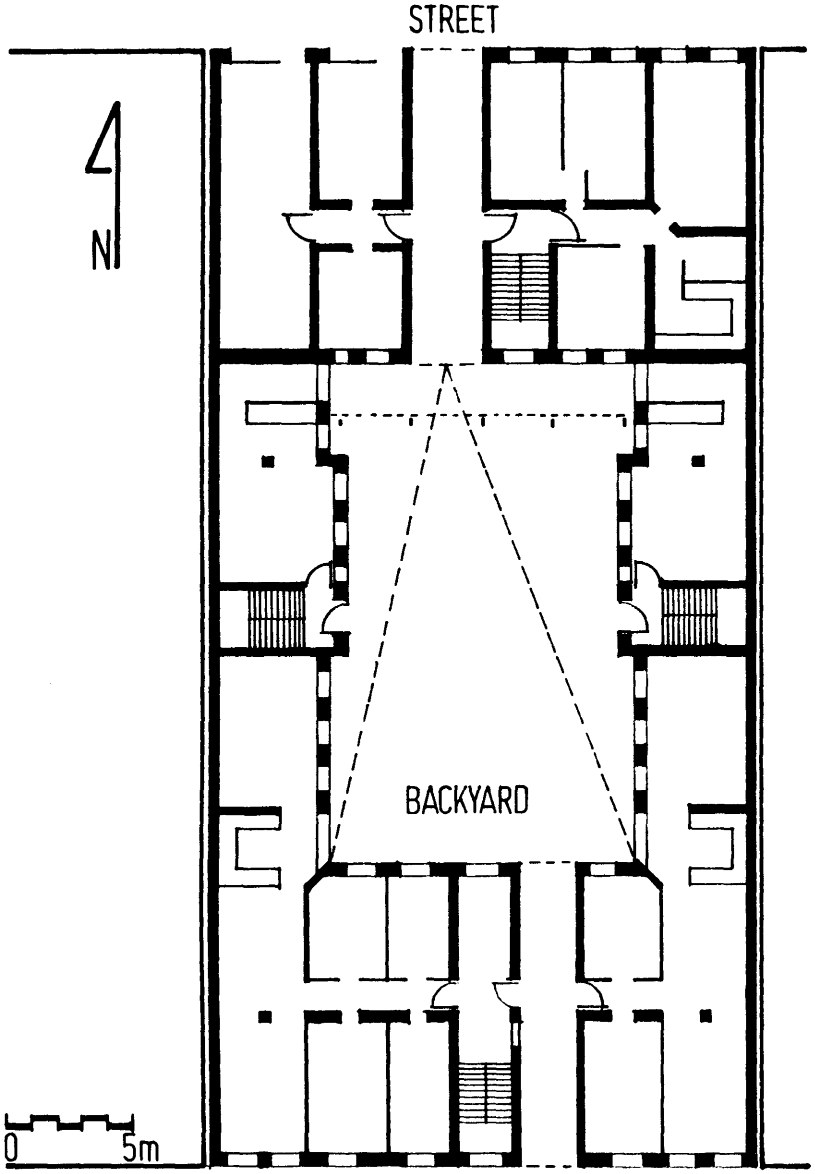


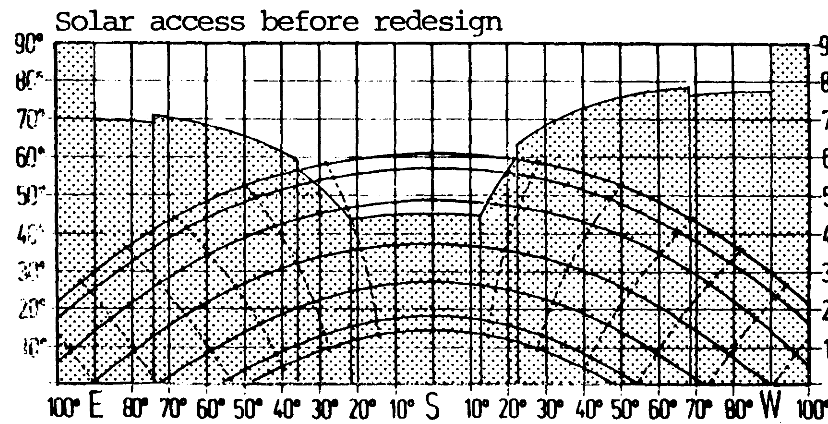
Fig.62 Turtle Bay Tower, New York

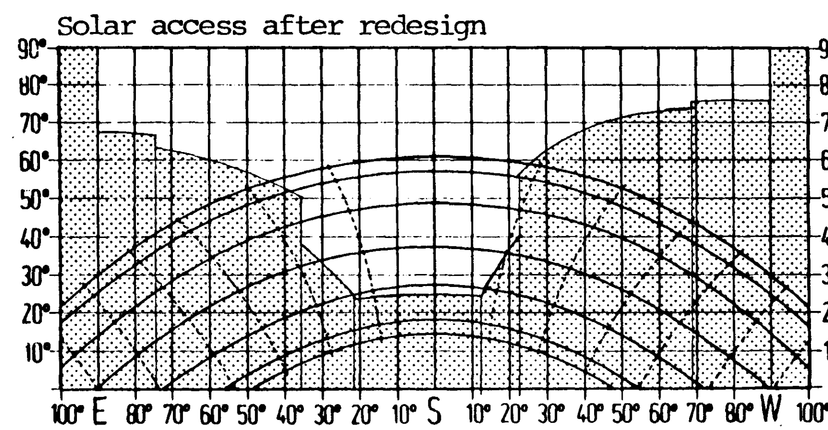
Adolf Loos proposed in 1923 a design for a high-density house configuration which took advantage of setbacks for the side-wings (Fig.61).[48]

The redesign (1977) of the Turtle-Bay-Tower (1927) in New York from an office building into apartments shows a similar approach [49]. Because setbacks occur on nearly every floor a glass-enclosed terrarium was located adajcent to almost each apartment providing an unexpected, yet pleasant experience for the inhabitants (Fig. 62).

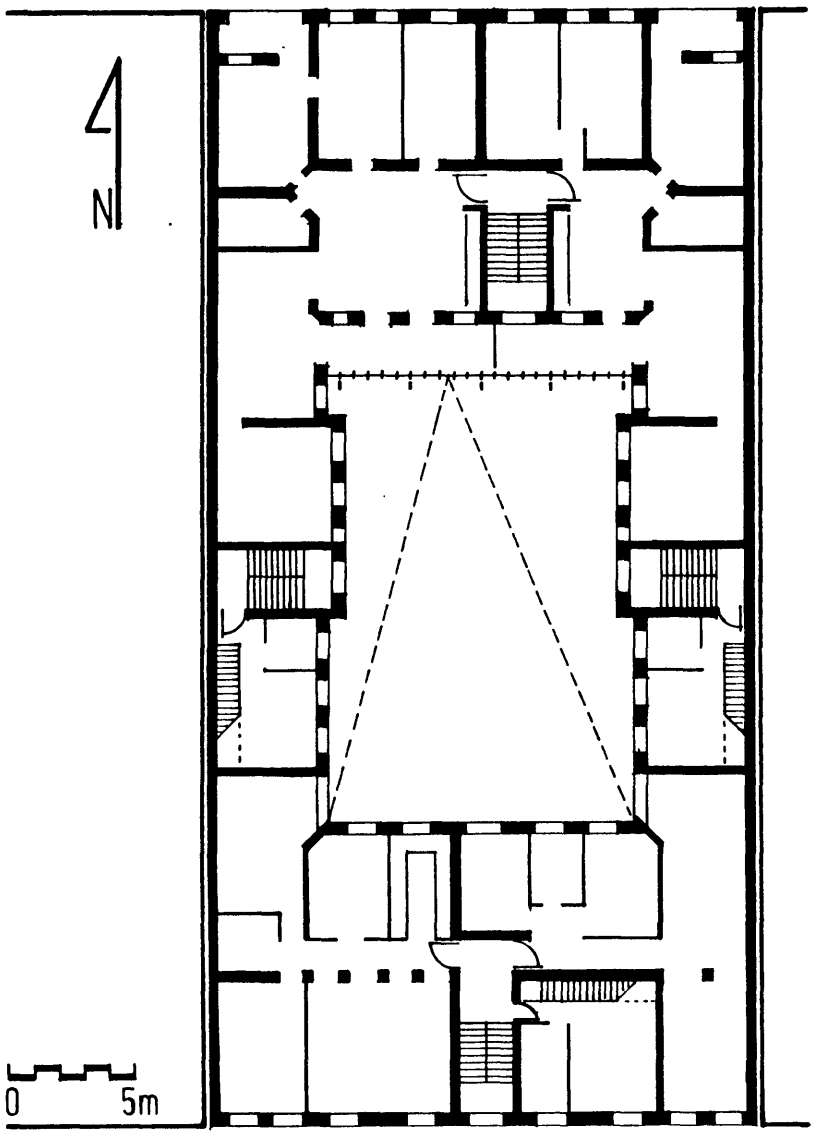
BUILDING A: REDESIGN 1.FLOOR

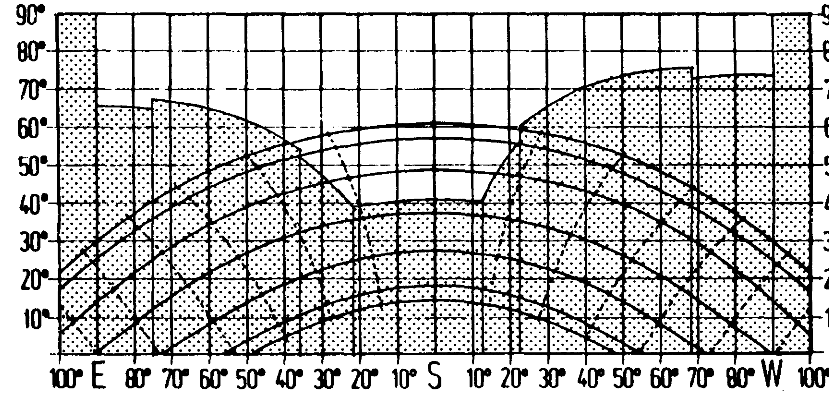


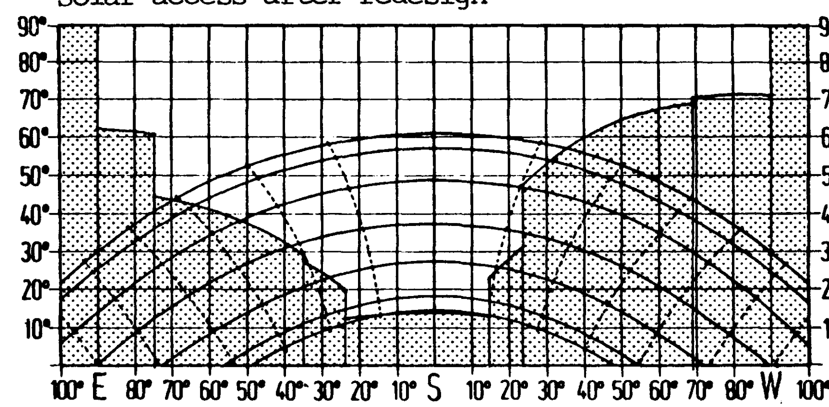


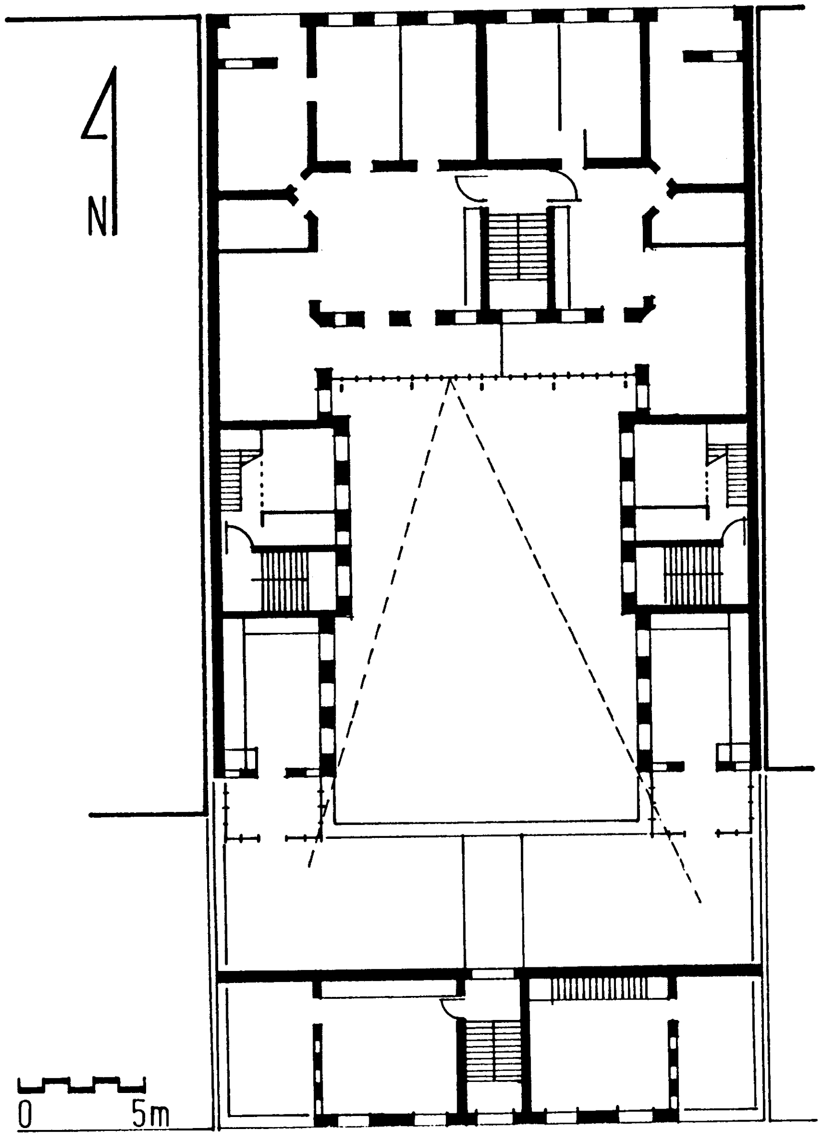


BUILDING A: REDESIGN 2.FLOOR

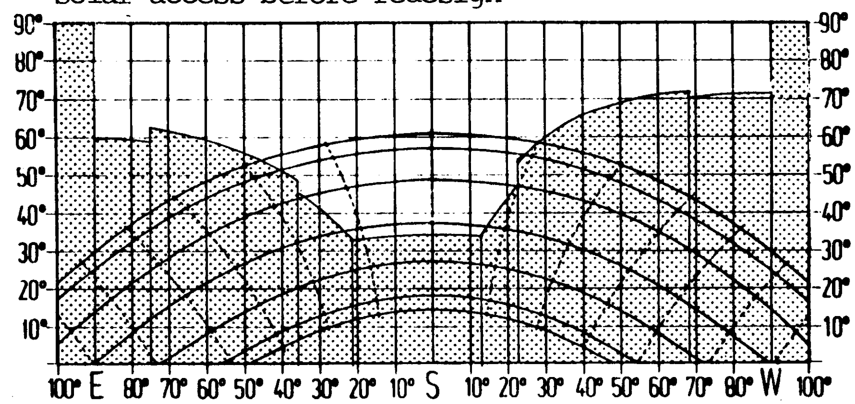




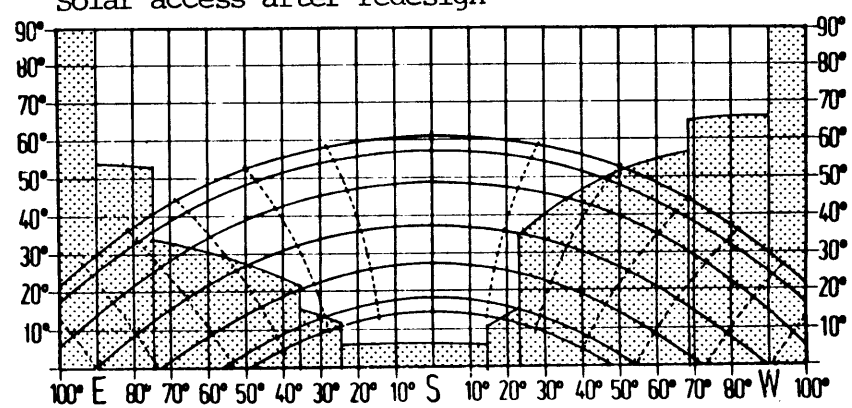


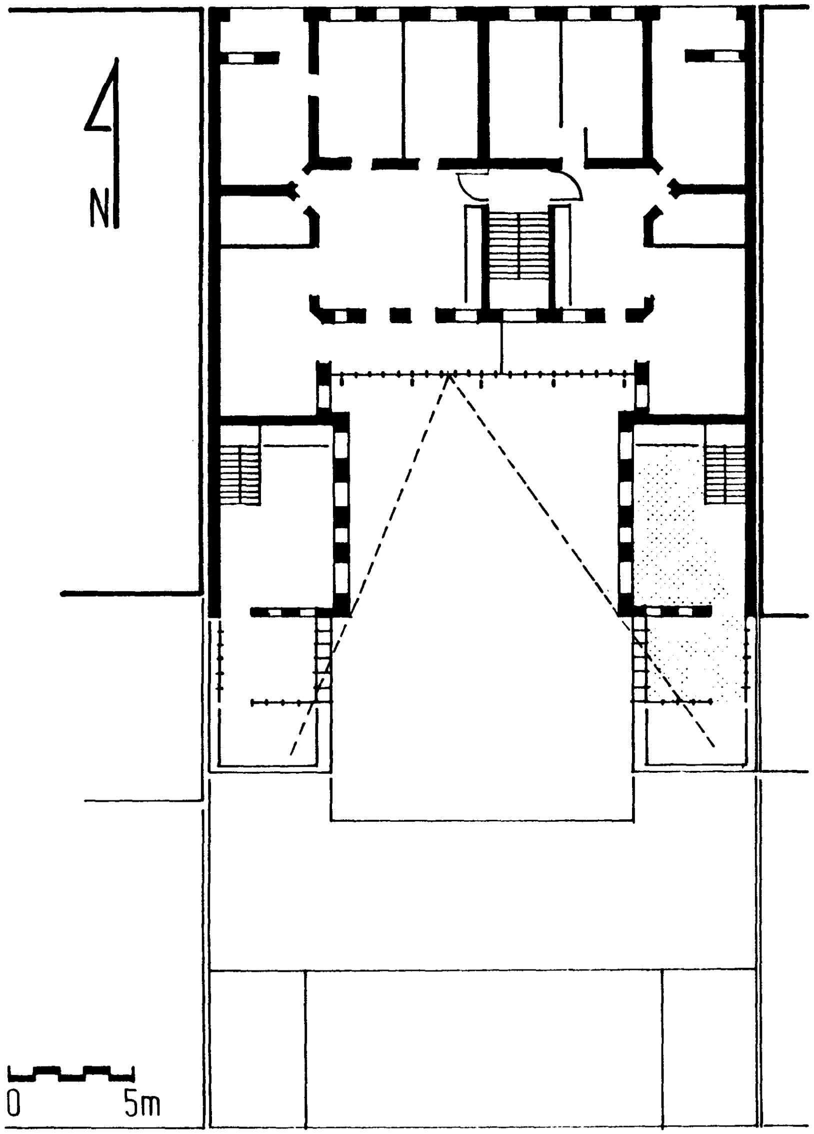


Solar access before redesign



Solar access after redesign





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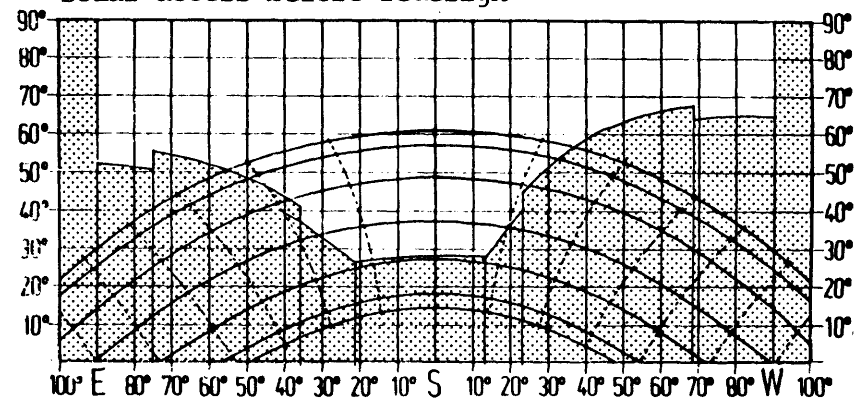

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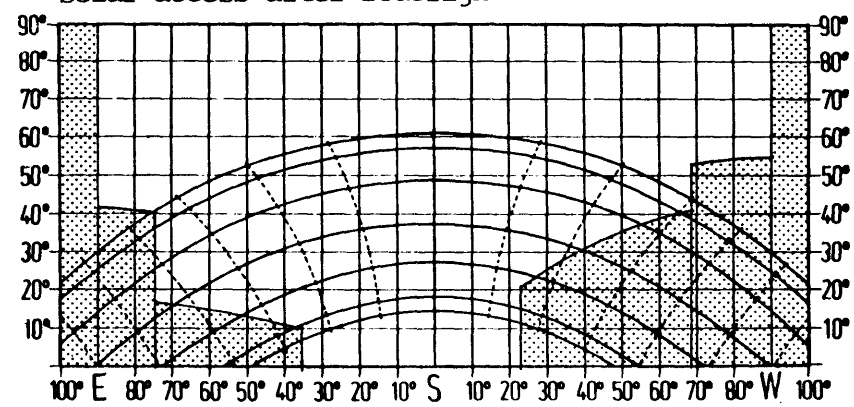

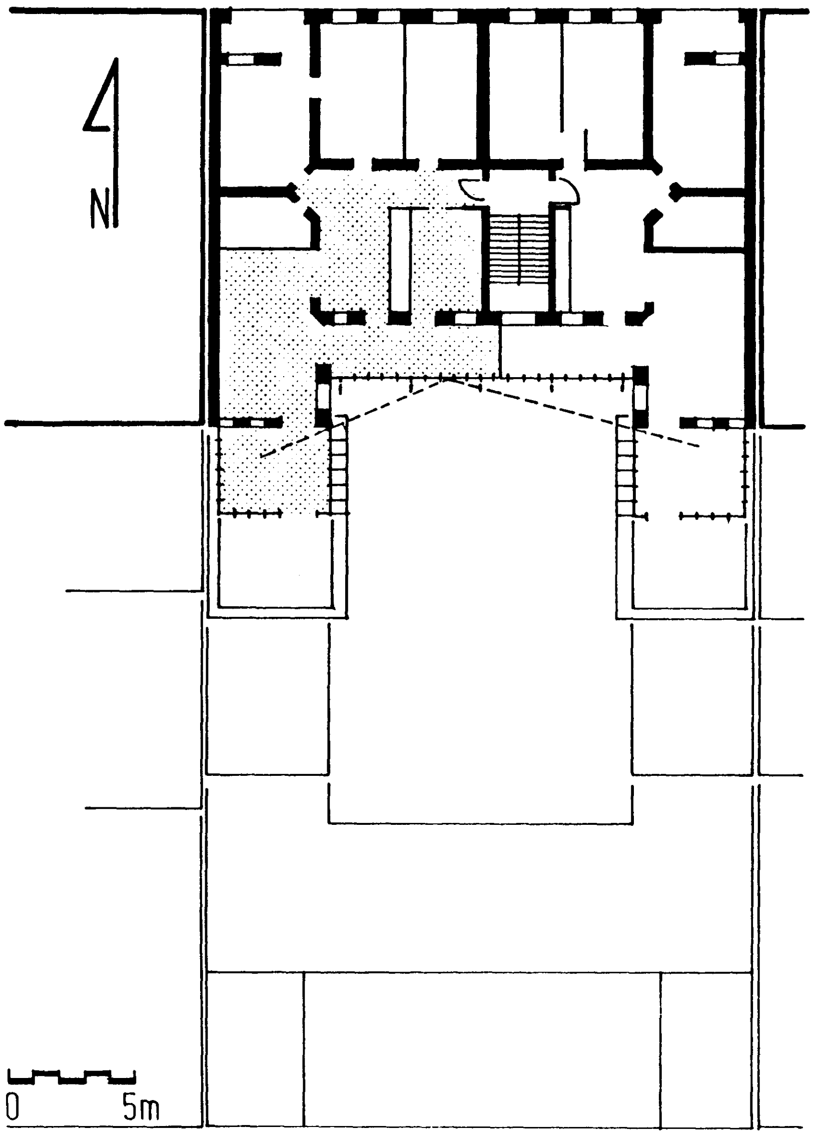

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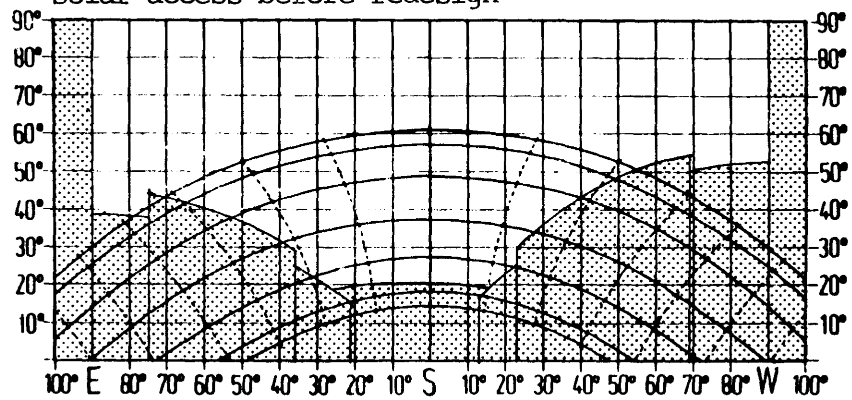

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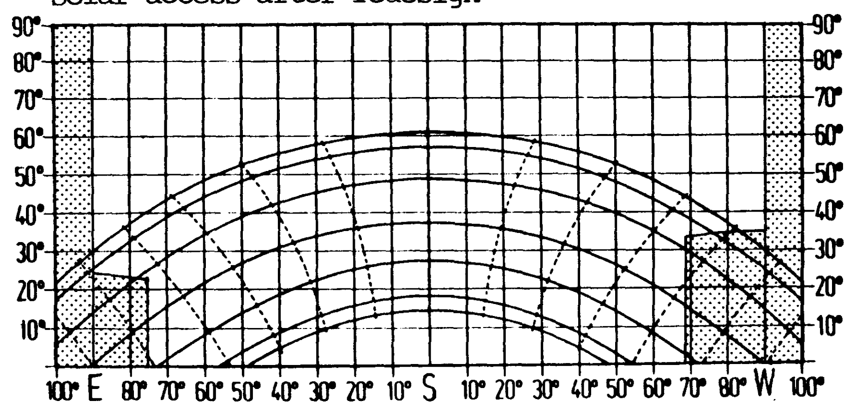

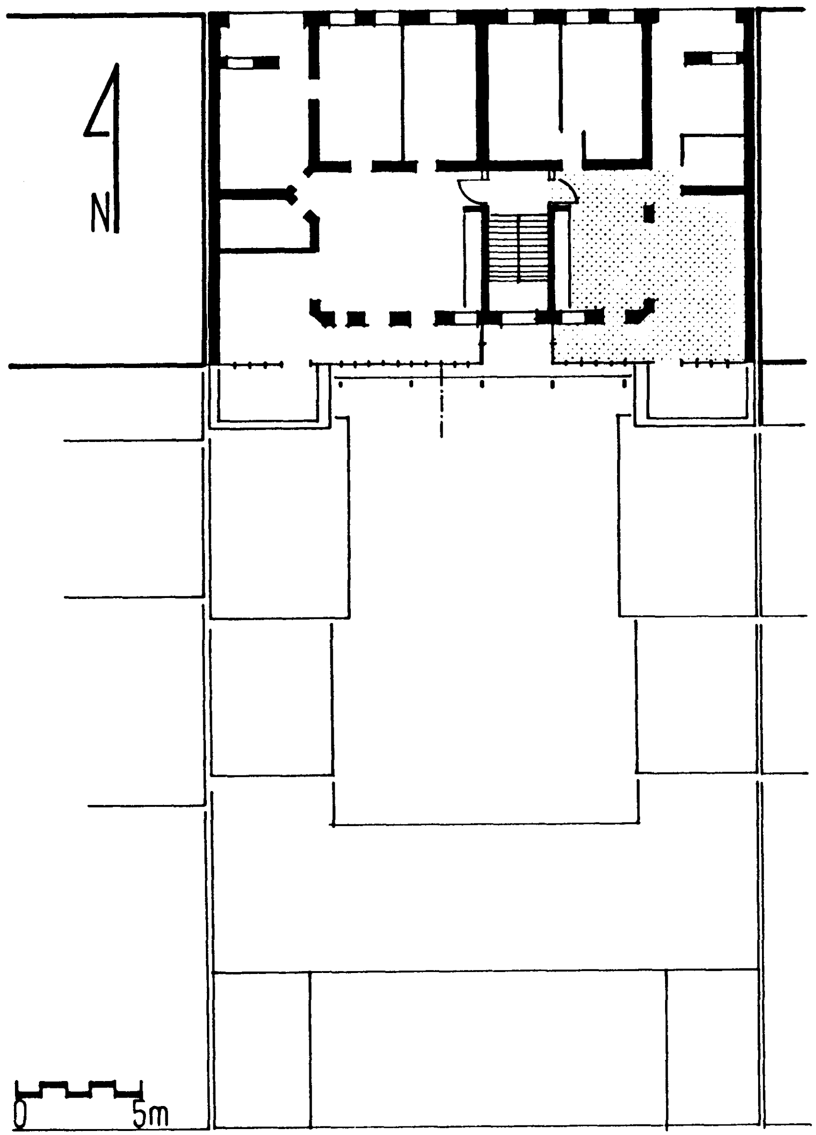

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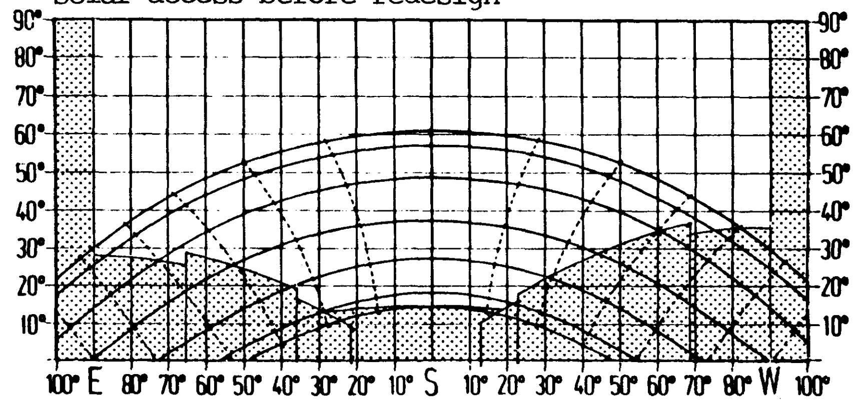
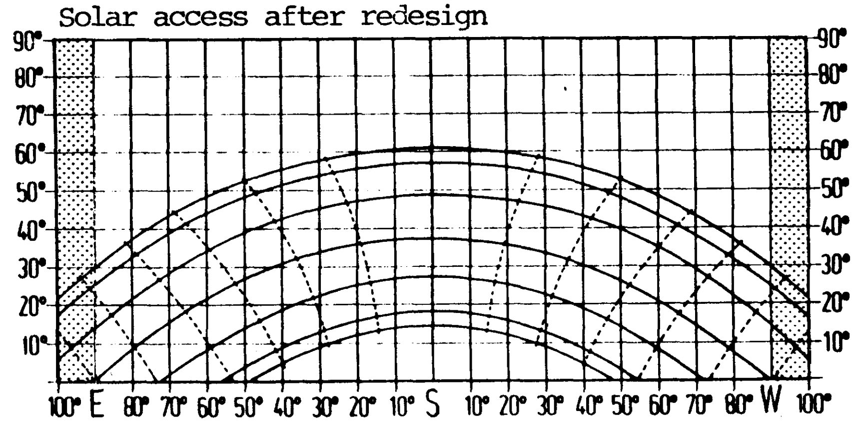


Solar access after redesign



1.FLOOR	January	February	March	April	May	June
diffuse (actual)	237 Wh/m^2 x = Wh/m^2	359 Wh/m^2 x = Wh/m^2	706 Wh/m^2 x = Wh/m^2	984 Wh/m^2 x = $Wh/m2$	1252 Wh/m^2 x = Wh/m^2	1371 Wh/m^2 x = Wh/m^2
global (actual)	1130 Wh/m^2 x = Wh/m^2	1622 Wh/m^2 x = Wh/m^2	2500 Wh/m^2 x = Wh/m^2	2525 Wh/m^2 x = Wh/m^2	2892 Wh/m^2 x = Wh/m^2	2992 Wh/m^2 x = Wh/m^2
global (clear day)	3615 Wh/m^2 x = Wh/m^2	4803 Wh/m^2 x = Wh/m^2	5069 Wh/m^2 x = Wh/m^2	4465 Wh/m^2 x = Wh/m^2	3928 Wh/m^2 x = Wh/m^2	3720 Wh/m^2 x = Wh/m^2

1.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369 Wh/m^2 x = Wh/m^2	1117 Wh/m^2 x = Wh/m^2	810 Wh/m^2 x = $Wh/m2$	492 Wh/m^2 x = Wh/m^2	271 Wh/m^2 x = Wh/m^2	178 Wh/m^2 x = Wh/m^2
global (actual)	3024 Wh/m^2 x = Wh/m^2	3143 Wh/m^2 x = Wh/m^2	2953 Wh/m^2 x = Wh/m^2	2162 Wh/m^2 x = Wh/m^2	1260 Wh/m^2 x = Wh/m^2	863 Wh/m^2 x = Wh/m^2
global (clear day)	3853 Wh/m^2 x = Wh/m^2	4300 Wh/m^2 x = Wh/m^2	4788 Wh/m^2 x = Wh/m^2	4563 Wh/m^2 x = Wh/m^2	3237 Wh/m^2 x = Wh/m^2	2956 Wh/m^2 x = Wh/m^2

2.FLOOR	January	February	March	April	May	June
diffuse (actual)	237 Wh/m^2 x = Wh/m^2	359 Wh/m^2 x = $Wh/m2$	706 Wh/m^2 x = Wh/m^2	984 Wh/m^2 x = $Wh/m2$	1252 Wh/m^2 x = Wh/m^2	1371 Wh/m^2 x = Wh/m^2
global (actual)	1130 Wh/m^2 x.55 = 622 Wh/m^2	1622 Wh/m^2 x.46 = 746 Wh/m^2	2500 Wh/m^2 x.54 = 1350 Wh/m^2	2525 Wh/m^2 x.53 = 1338 Wh/m^2	2892 Wh/m^2 x.60 = 1735 Wh/m^2	2992 Wh/m^2 x.60 = 1795 Wh/m^2
global (clear day)	3615 Wh/m^2 x.55 = 1988 Wh/m^2	4803 Wh/m^2 x.46 = 2209 Wh/m^2	5069 Wh/m^2 x.54 = 2737 Wh/m^2	4465 Wh/m^2 x.53 = 2366 Wh/m^2	3928 Wh/m^2 x.60 = 2359 Wh/m^2	3720 Wh/m^2 x.60 = 2232 Wh/m^2

2.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369 Wh/m^2 x = Wh/m^2	1117 Wh/m^2 x = Wh/m^2	810 $Wh/m2$ x = $Wh/m2$	492 Wh/m^2 x = Wh/m^2	271 Wh/m^2 x = Wh/m^2	178 Wh/m^2 x = Wh/m^2
global (actual)	3024 Wh/m^2 x.60 = 1814 Wh/m^2	3143 Wh/m^2 x.53 = 1666 Wh/m^2	2953 Wh/m^2 x.54 = 1595 Wh/m^2	2162 Wh/m^2 x.46 = 995 Wh/m^2	1260 Wh/m^2 x.55 = 693 Wh/m^2	863 Wh/m^2 x.60 = 518 Wh/m^2
global (clear day)	3853 Wh/m^2 x.60 = 2312 Wh/m^2	4300 Wh/m^2 x.53 = 2279 Wh/m^2	4788 Wh/m^2 x.54 = 2586 Wh/m^2	4563 Wh/m^2 x.46 = 2099 Wh/m^2	3237 Wh/m^2 x.55 = 1780 Wh/m^2	2956 Wh/m^2 x.60 = 1774 Wh/m^2

3.FLOOR	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x = Wh/m^2	359Wh/m^2 x = Wh/m^2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m^2	1252Wh/m^2 x = Wh/m^2	1371Wh/m^2 x = Wh/m^2
global (actual)	1130Wh/m^2 x.69 = 780 Wh/m^2	1622Wh/m^2 x.59 = 957 Wh/m^2	2500Wh/m^2 x.54 = 1350 Wh/m^2	2525Wh/m^2 x.62 = 1565 Wh/m^2	2892Wh/m^2 x.73 = 2111 Wh/m^2	2992Wh/m^2 x.71 = 2124 Wh/m^2
global (clear day)	3615Wh/m^2 x.69 = 2494 Wh/m^2	4803Wh/m^2 x.59 = 2834 Wh/m^2	5069Wh/m^2 x.54 = 2737 Wh/m^2	4465Wh/m^2 x.62 = 2768 Wh/m^2	3928Wh/m^2 x.73 = 2867 Wh/m^2	3720Wh/m^2 x.71 = 2641 Wh/m^2

3.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m^2 x = Wh/m^2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x = Wh/m^2	178Wh/m^2 x = Wh/m^2
global (actual)	3024Wh/m^2 x.73 = 2207 Wh/m^2	3143Wh/m^2 x.62 = 1949 Wh/m^2	2953Wh/m^2 x.54 = 1595 Wh/m^2	2162Wh/m^2 x.59 = 1276 Wh/m^2	1260Wh/m^2 x.69 = 869 Wh/m^2	863Wh/m^2 x.60 = 518 Wh/m^2
global (clear day)	3853Wh/m^2 x.73 = 2813 Wh/m^2	4300Wh/m^2 x.62 = 2666 Wh/m^2	4788Wh/m^2 x.54 = 2586 Wh/m^2	4563Wh/m^2 x.59 = 2692 Wh/m^2	3237Wh/m^2 x.69 = 2234 Wh/m^2	2956Wh/m^2 x.60 = 1774 Wh/m^2

4.FLOOR	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x = Wh/m^2	359Wh/m^2 x = Wh/m^2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m^2	1252Wh/m^2 x = Wh/m^2	1371Wh/m^2 x = Wh/m^2
global (actual)	1130Wh/m^2 x.69 = 780 Wh/m^2	1622Wh/m^2 x.68 = 1103 Wh/m^2	2500Wh/m^2 x.81 = 2025 Wh/m^2	2525Wh/m^2 x.79 = 1995 Wh/m^2	2892Wh/m^2 x.81 = 2343 Wh/m^2	2992Wh/m^2 x.80 = 2394 Wh/m^2
global (clear day)	3615Wh/m^2 x.69 = 2494 Wh/m^2	4803Wh/m^2 x.68 = 3266 Wh/m^2	5069Wh/m^2 x.81 = 4106 Wh/m^2	4465Wh/m^2 x.79 = 3527 Wh/m^2	3928Wh/m^2 x.81 = 3182 Wh/m^2	3720Wh/m^2 x.80 = 2976 Wh/m^2

4.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m^2 x = Wh/m^2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x = Wh/m^2	178Wh/m^2 x = Wh/m^2
global (actual)	3024Wh/m^2 x.81 = 2449 Wh/m^2	3143Wh/m^2 x.79 = 2483 Wh/m^2	2953Wh/m^2 x.81 = 2392 Wh/m^2	2162Wh/m^2 x.68 = 1470 Wh/m^2	1260Wh/m^2 x.69 = 869 Wh/m^2	863Wh/m^2 x.75 = 647 Wh/m^2
global (clear day)	3853Wh/m^2 x.81 = 3121 Wh/m^2	4300Wh/m^2 x.79 = 3397 Wh/m^2	4788Wh/m^2 x.81 = 3878 Wh/m^2	4563Wh/m^2 x.68 = 3103 Wh/m^2	3237Wh/m^2 x.69 = 2233 Wh/m^2	2956Wh/m^2 x.75 = 2217 Wh/m^2

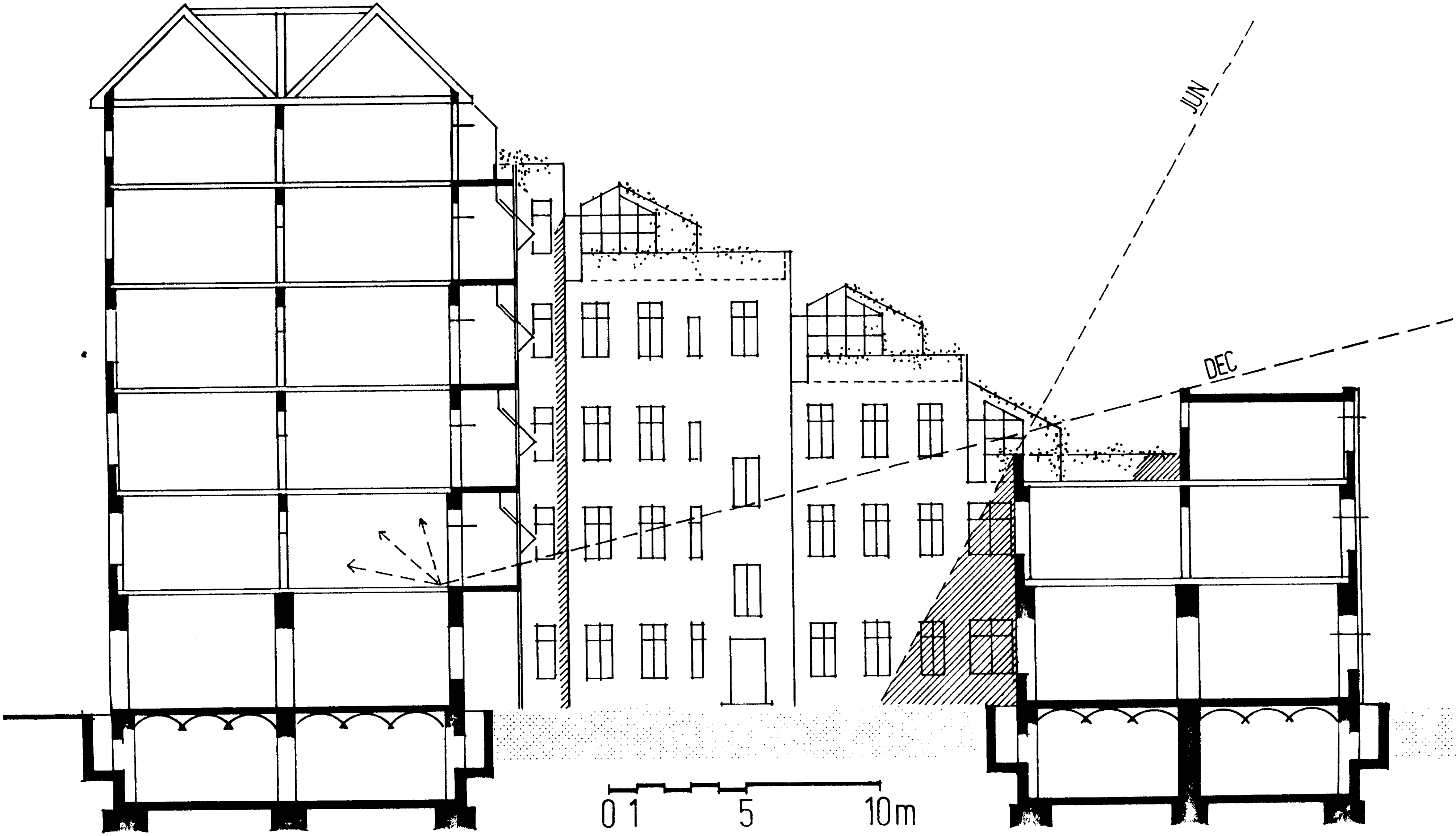
5.FLOOR	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x = Wh/m^2	359Wh/m^2 x = Wh/m2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m2	1252Wh/m2 x = Wh/m2	1371Wh/m2 x = Wh/m^2
global (actual)	1130Wh/m^2 x 1.0 = Wh/m^2	1622Wh/m^2 x 1.0 = Wh/m2	2500Wh/m^2 x .96 = 2400 Wh/m^2	2525Wh/m2 x.88 = 2222 Wh/m^2	2892Wh/m^2 x.88 = 2545 Wh/m^2	2992Wh/m^2 x.85 = 2543 Wh/m^2
global (clear day)	3615Wh/m^2 x 1.0 = Wh/m^2	4803Wh/m^2 x 1.0 = Wh/m^2	5069Wh/m^2 x .96 = 4866 Wh/m^2	4465Wh/m^2 x.88 = 3929 Wh/m^2	3928Wh/m^2 x.88 = 3457 Wh/m^2	3720Wh/m^2 x.85 = 3162 Wh/m^2

5.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m2 x = Wh/m2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x = Wh/m^2	178Wh/m2 x = Wh/m^2
global (actual)	3024Wh/m^2 x.88 = 2661 Wh/m^2	3143Wh/m^2 x.88 = 2766 Wh/m^2	2953Wh/m^2 x.96 = 2835 Wh/m^2	2162Wh/m^2 x 1.0 = Wh/m^2	1260Wh/m^2 x 1.0 = Wh/m^2	863Wh/m^2 x 1.0 = Wh/m^2
global (clear day)	3853Wh/m^2 x.88 = 3391 Wh/m^2	4300Wh/m^2 x.88 = 3784 Wh/m^2	4788Wh/m^2 x.96 = 4596 Wh/m^2	4563Wh/m^2 x 1.0 = Wh/m^2	3237Wh/m^2 x 1.0 = Wh/m^2	2956Wh/m^2 x 1.0 = Wh/m^2

6.FLOOR	January	February	March	April	May	June
diffuse (actual)	237Wh/m^2 x = Wh/m^2	359Wh/m^2 x = Wh/m^2	706Wh/m^2 x = Wh/m^2	984Wh/m^2 x = Wh/m2	1252Wh/m2 x = Wh/m^2	1371Wh/m2 x = Wh/m^2
global (actual)	1130Wh/m^2 x 1.0 = Wh/m^2	1622Wh/m^2 x 1.0 = Wh/m^2	2500Wh/m^2 x 1.0 = Wh/m^2	2525Wh/m2 x.99 = 2499 Wh/m^2	2892Wh/m^2 x.92 = 2661 Wh/m^2	2992Wh/m^2 x.90 = 2693 Wh/m^2
global (clear day)	3615Wh/m^2 x 1.0 = Wh/m^2	4803Wh/m^2 x 1.0 = Wh/m^2	5069Wh/m^2 x 1.0 = Wh/m^2	4465Wh/m^2 x .99 = 4420 Wh/m^2	3928Wh/m^2 x.92 = 3614 Wh/m^2	3720Wh/m^2 x.90 = 3348 Wh/m^2

6.FLOOR	July	August	September	October	November	December
diffuse (actual)	1369Wh/m^2 x = Wh/m^2	1117Wh/m^2 x = Wh/m^2	810Wh/m2 x = Wh/m2	492Wh/m^2 x = Wh/m^2	271Wh/m^2 x = Wh/m^2	178Wh/m2 x = Wh/m^2
global (actual)	3024Wh/m^2 x.92 = 2782 Wh/m^2	3143Wh/m^2 x.99 = 3112 Wh/m^2	2953Wh/m^2 x 1.0 = Wh/m^2	2162Wh/m^2 x 1.0 = Wh/m^2	1260Wh/m^2 x 1.0 = Wh/m^2	863Wh/m^2 x 1.0 = Wh/m^2
global (clear day)	3853Wh/m^2 x.92 = 3545 Wh/m^2	4300Wh/m2 x.99 = 4257 Wh/m^2	4788Wh/m^2 x 1.0 = Wh/m^2	4563Wh/m^2 x 1.0 = Wh/m^2	3237Wh/m^2 x 1.0 = Wh/m^2	2956Wh/m^2 x 1.0 = Wh/m^2

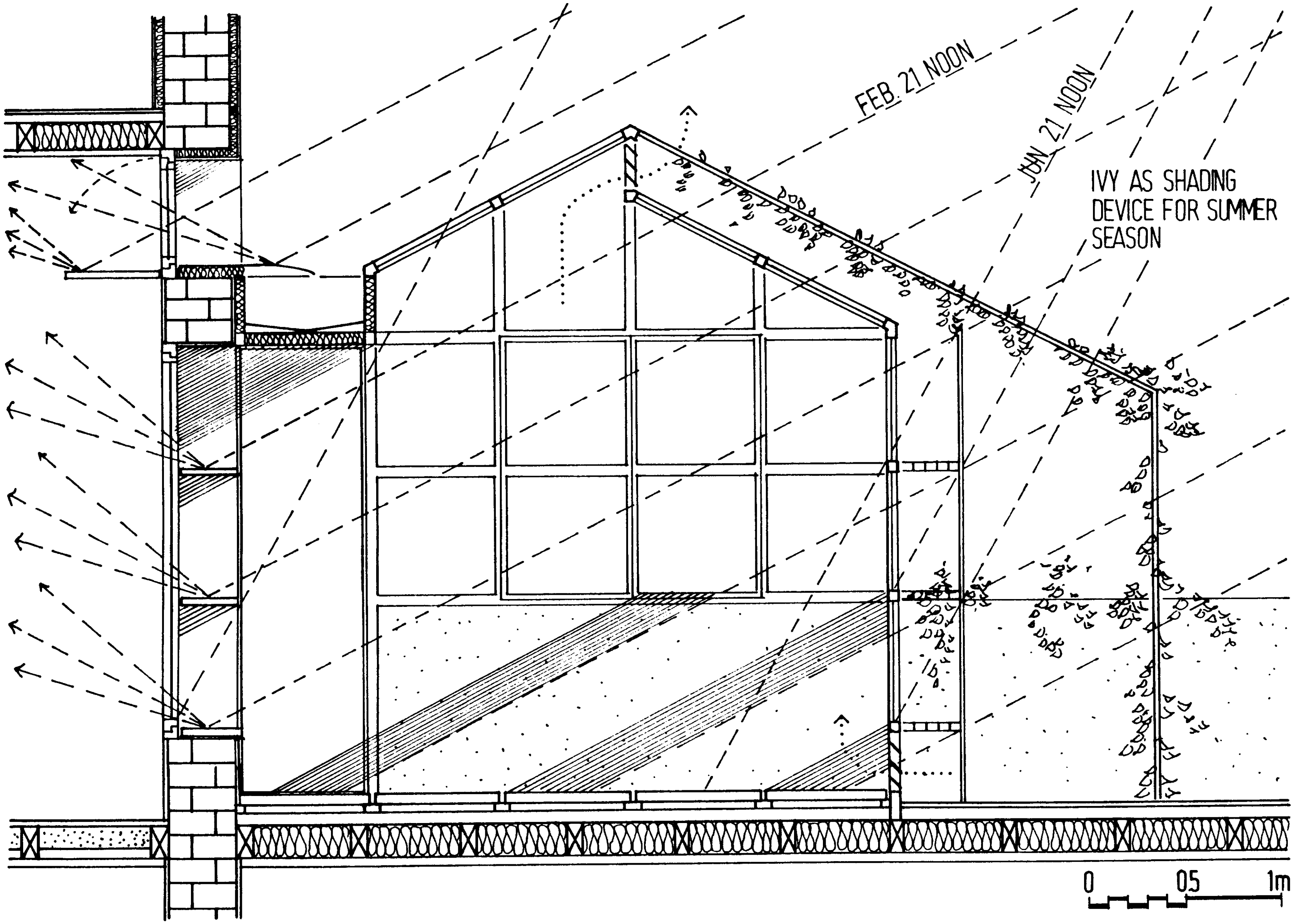
BUILDING A: REDESIGN SECTION

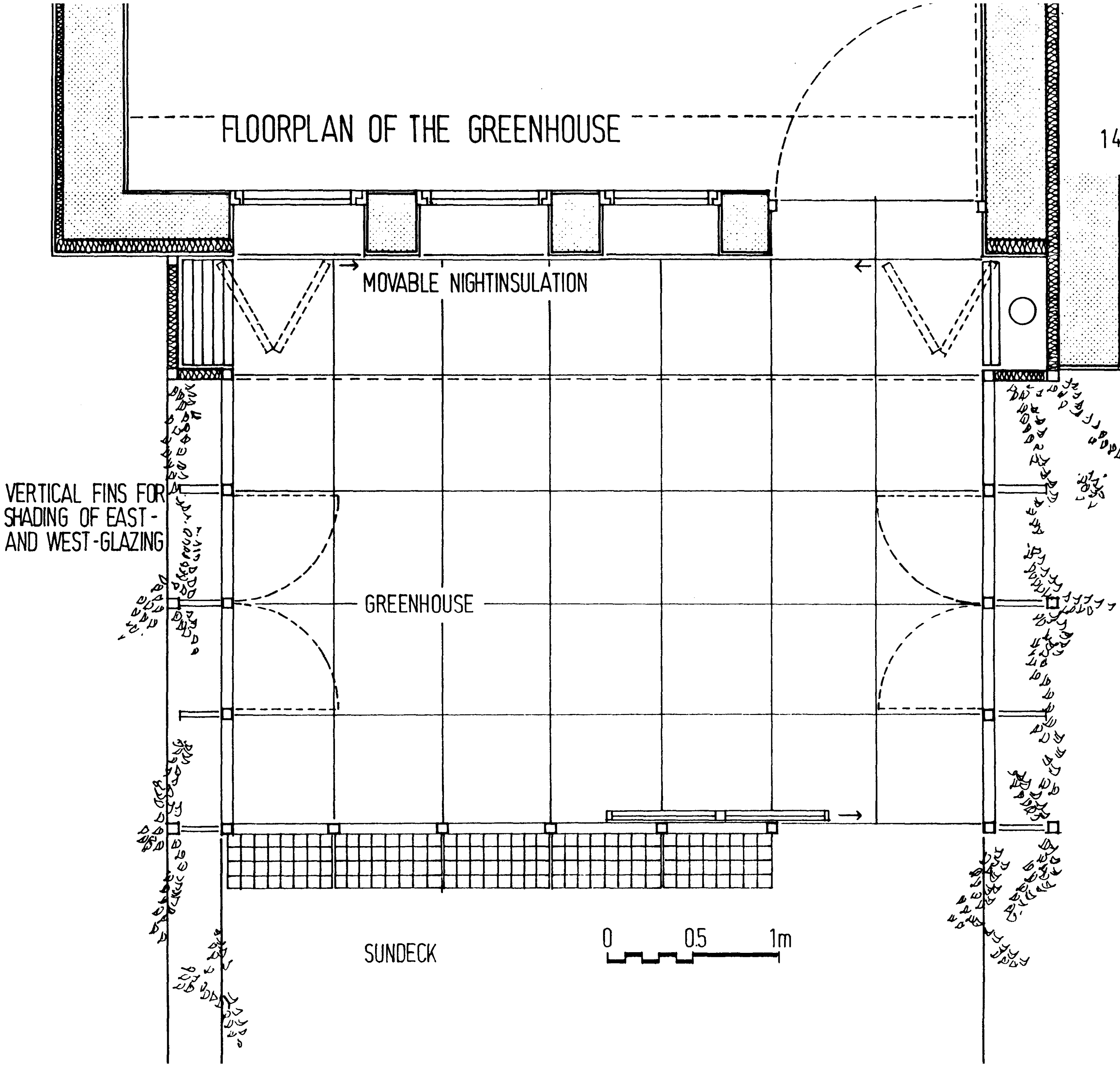


Solar Design

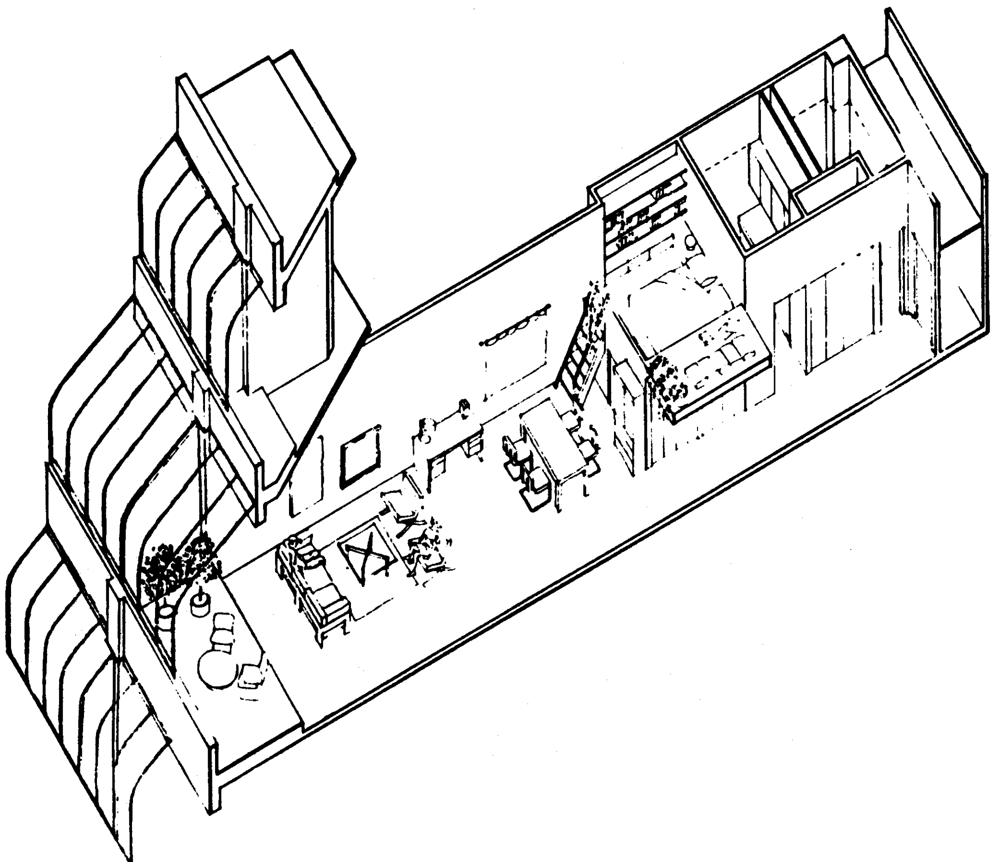
"Solar design is not always apparent especially when the passive approach is taken. Neither does it dictate any particular style. However, the sun makes its own terms, and must be acknowledged. The response to these terms is most apparent in sections of solar buildings, most particulary in south-north sections. For better or worse, this is where the designer must begin". [50]
All sections in this thesis represent south-north sections through streets, buildings or building parts. The sun's angles of incidence during winter ans summer months for the location of Berlin are drawn to illustrate their impact on the design probelm as well as the redesign on these different sun angles. Building form itself, orientation and window size and configuration should allow the sun to enter the living spaces during the winter months and should gradually reduce their impact during spring and even more as mid-summer approaches.
In the second half of the year the situation is reversed.

SECTION THROUGH THE GREENHOUSE (BUILDING A: 4.+5. FLOOR)

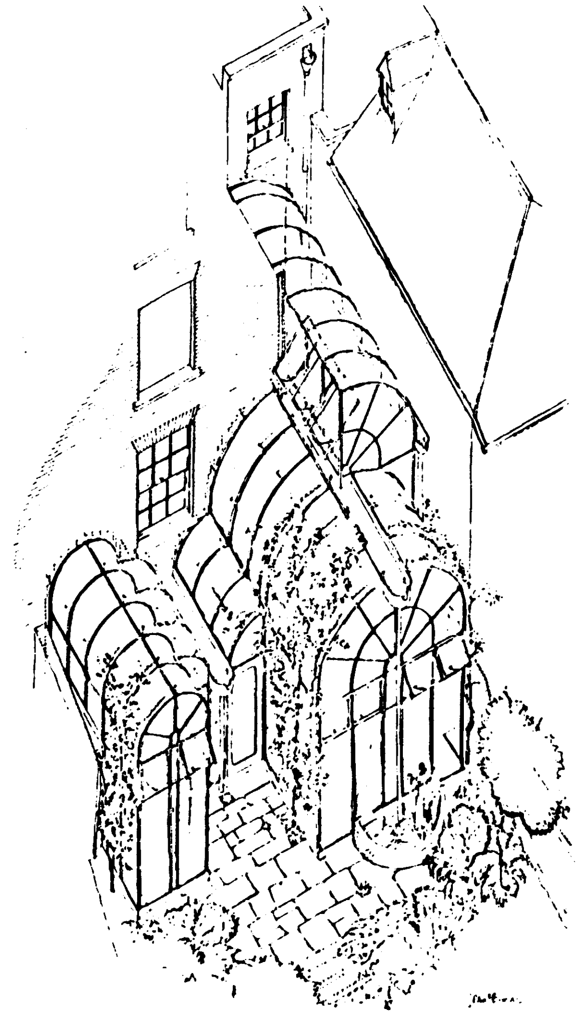



FLOORPLAN OF THE GREENHOUSE
MOVABLE NIGHTINSULATION
VERTICAL FINS FOR SHADING OF EAST- AND WEST-GLAZING
GREENHOUSE
SUNDECK
0
0.5
1m

Glashouse additions can be done in quite different ways as these two examples show:

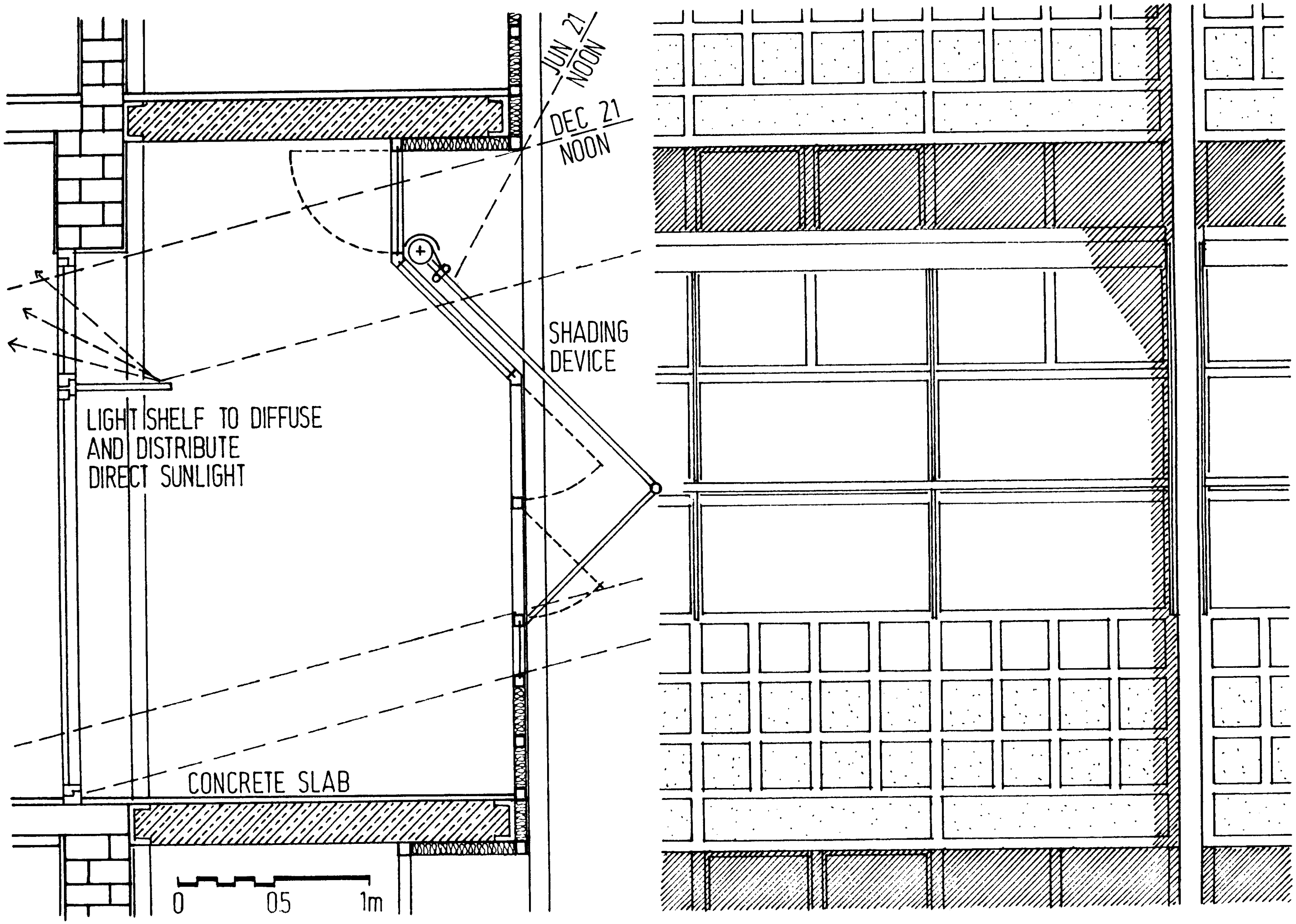


Turtle Bay Tower, New York
Section through an apartment
(from: Architecural Record, Sep.1977)

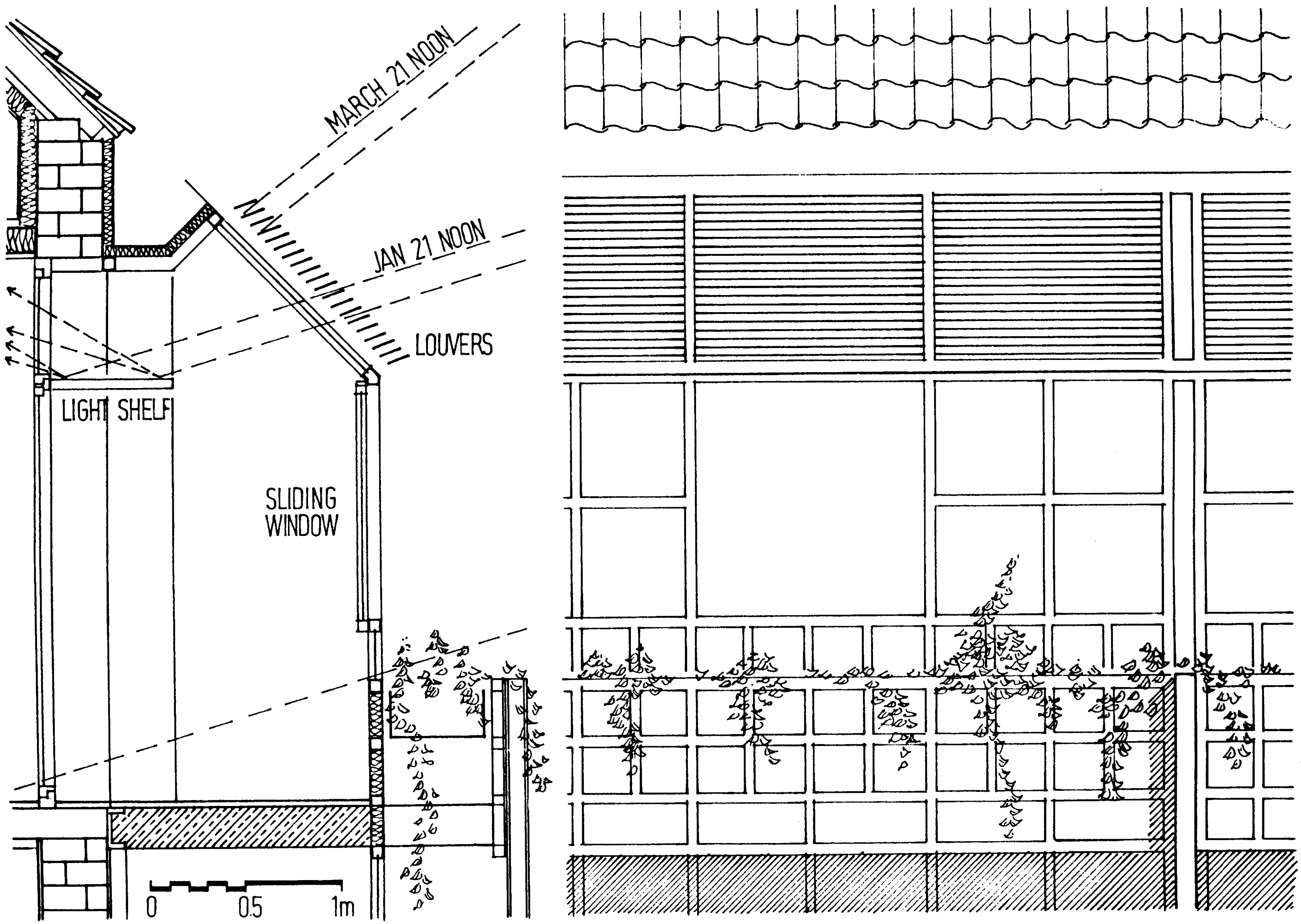


House extension in Hampstead, London
(from: Architectural Review, Jan.80)

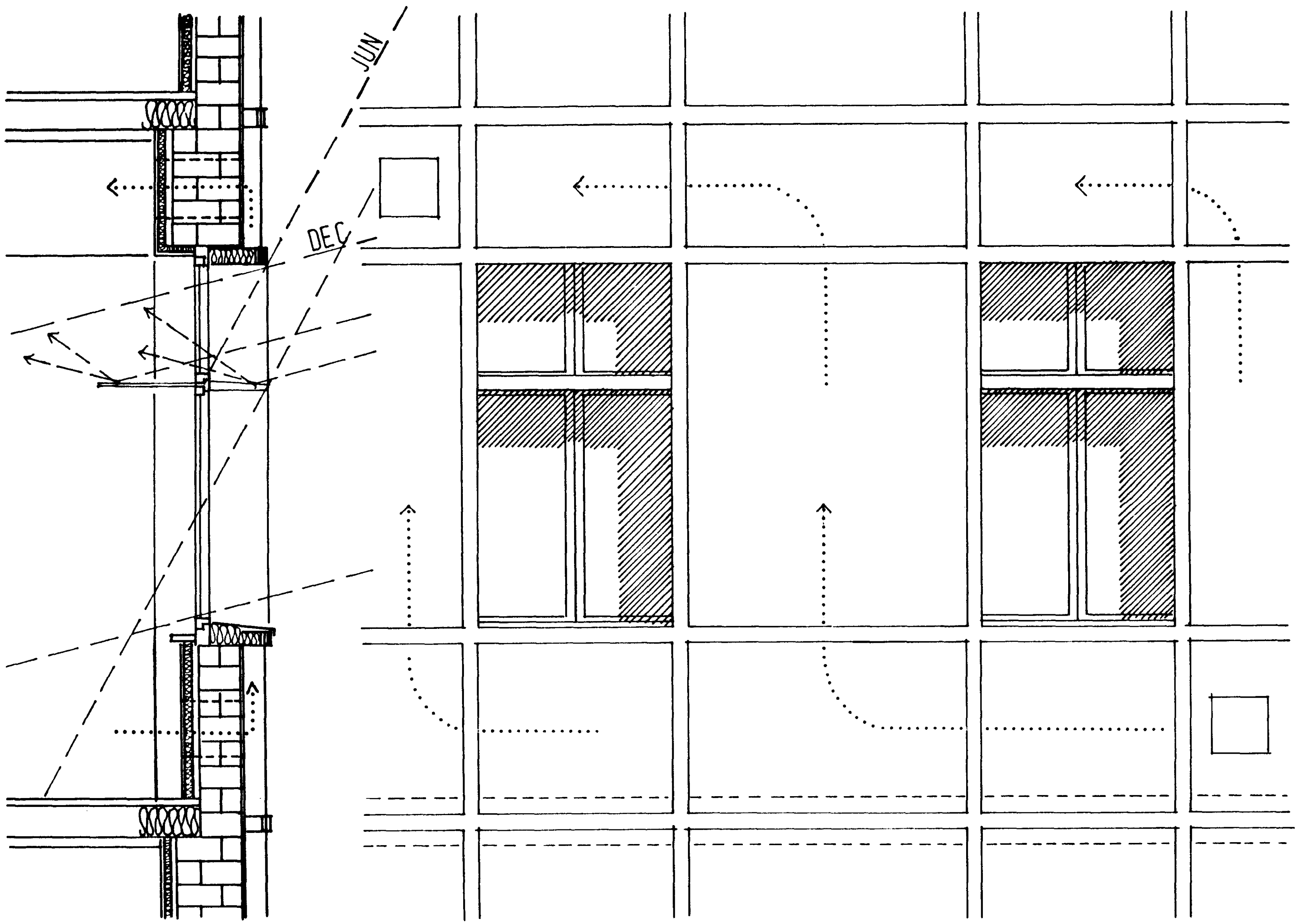
SECTION AND ELEVATION OF SUNSPACE (BUILDING A: 2.-5. FLOOR)

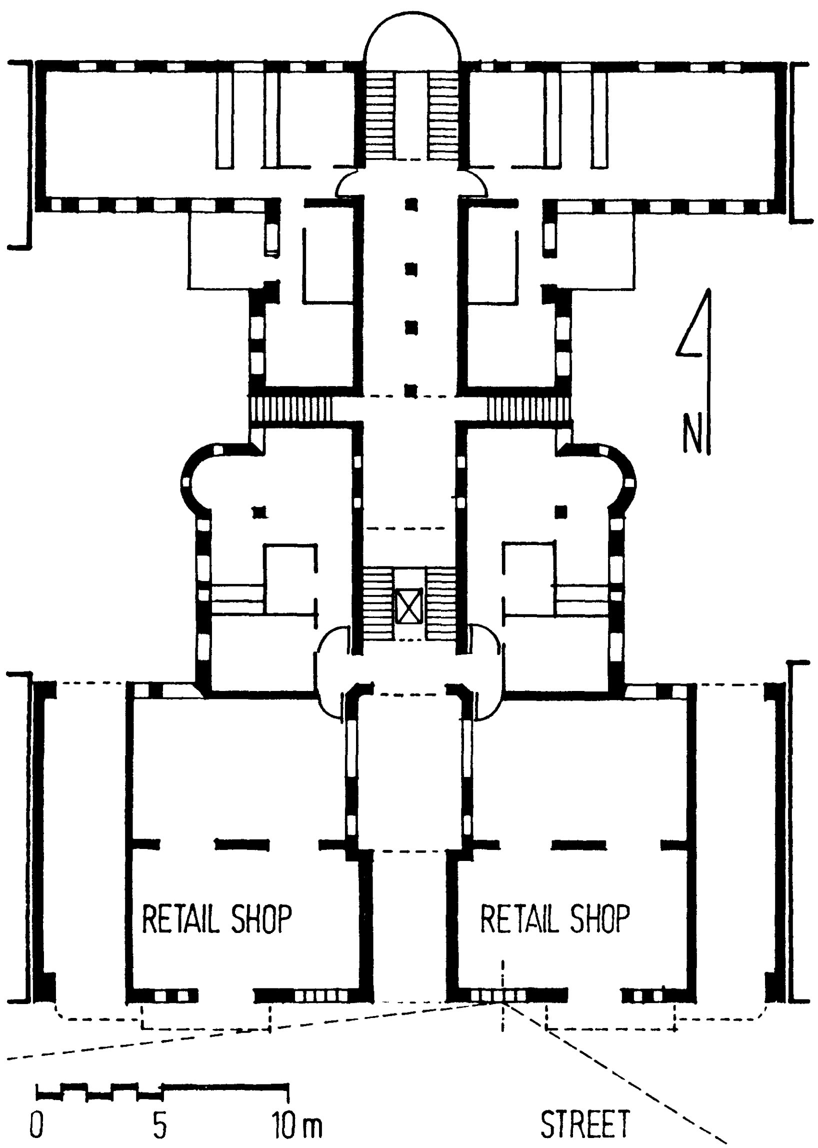


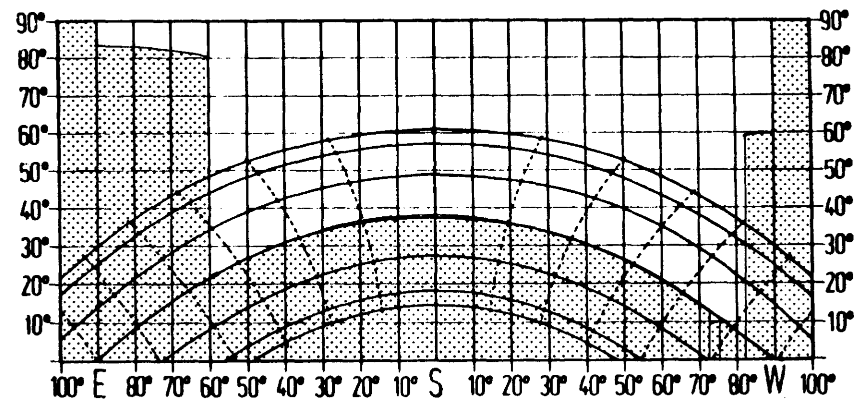
SECTION AND ELEVATION OF SUNSPACE (BUILDING A: 6.FLOOR)



PASSIVE INDIRECT SOLAR GAIN MASS WALL SYSTEM (BUILDING A: BACKHOUSE)




N
RETAIL SHOP
RETAIL SHOP
0
5
10 m
STREET


90°
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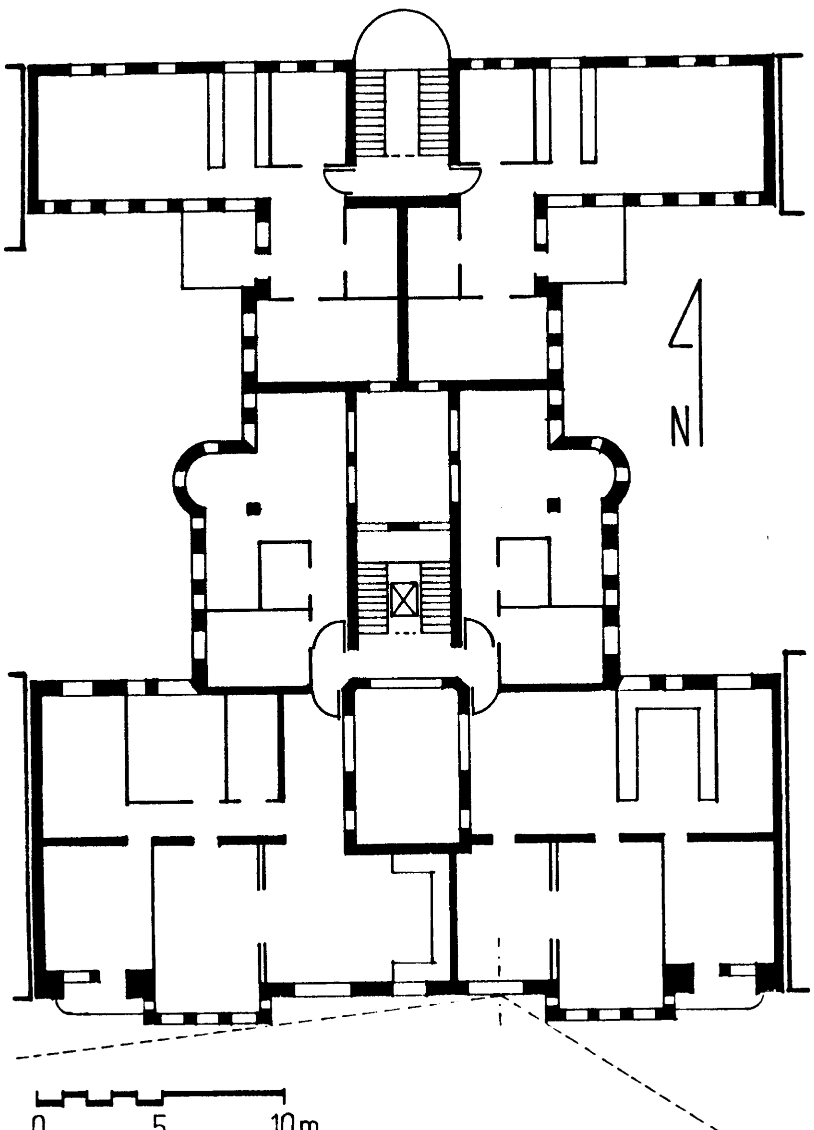
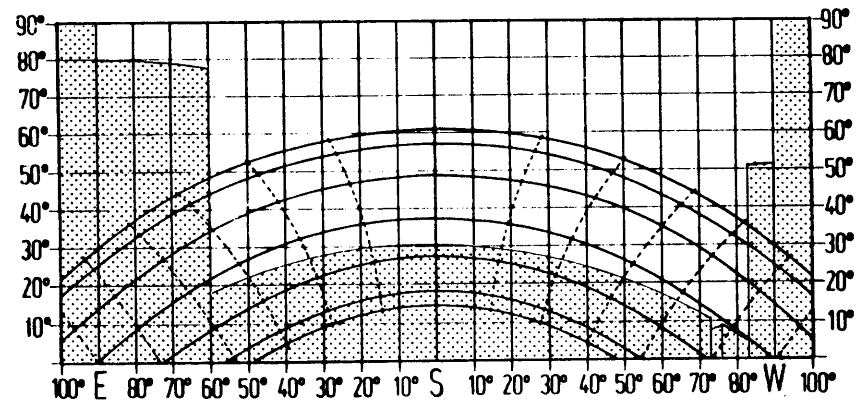
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°


N
0
5
10m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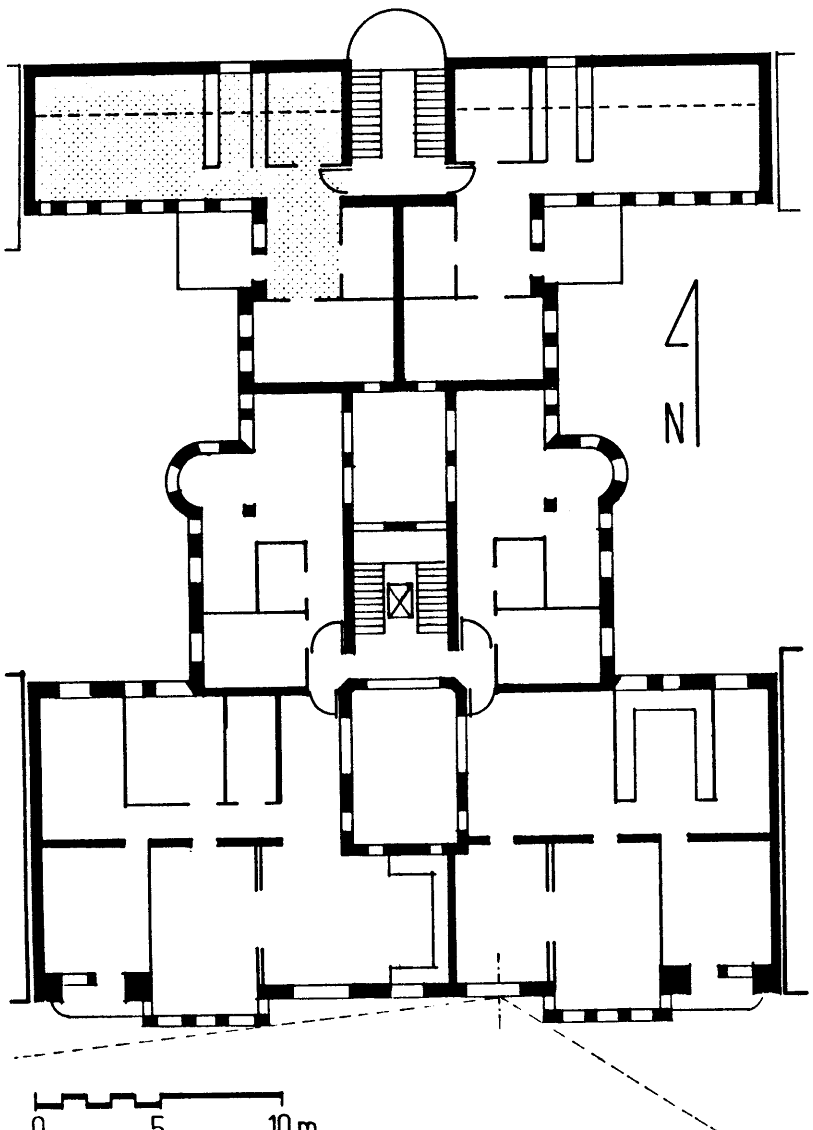
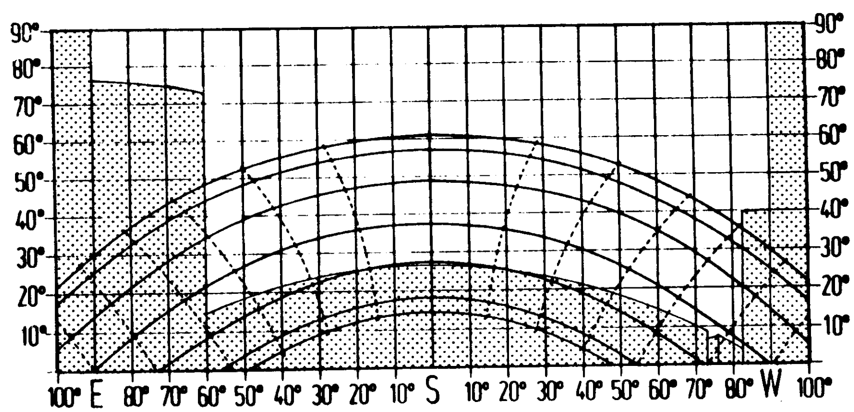

N
0
5
10 m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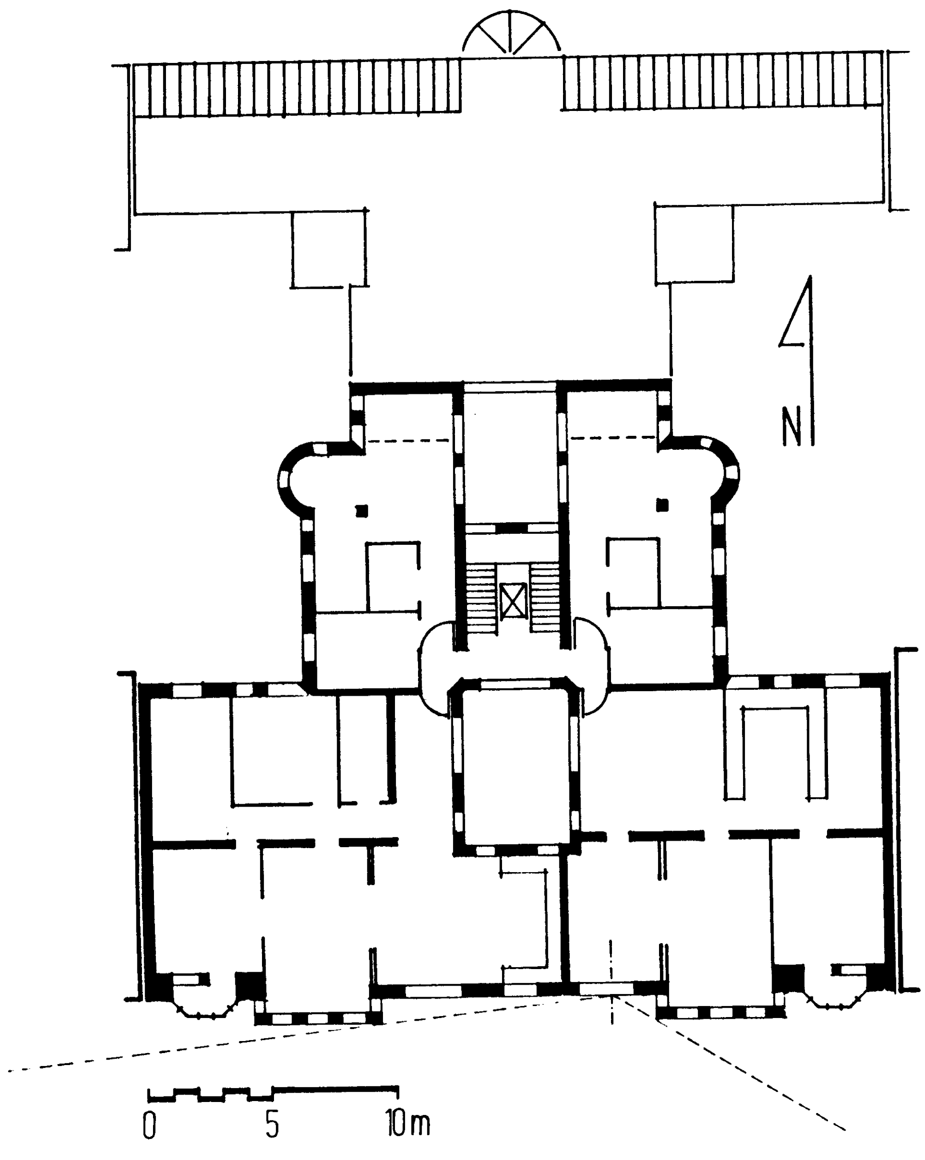
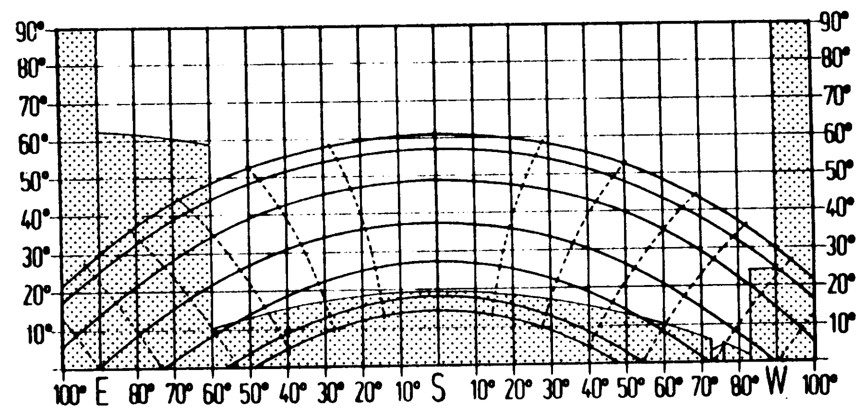

N
0
5
10m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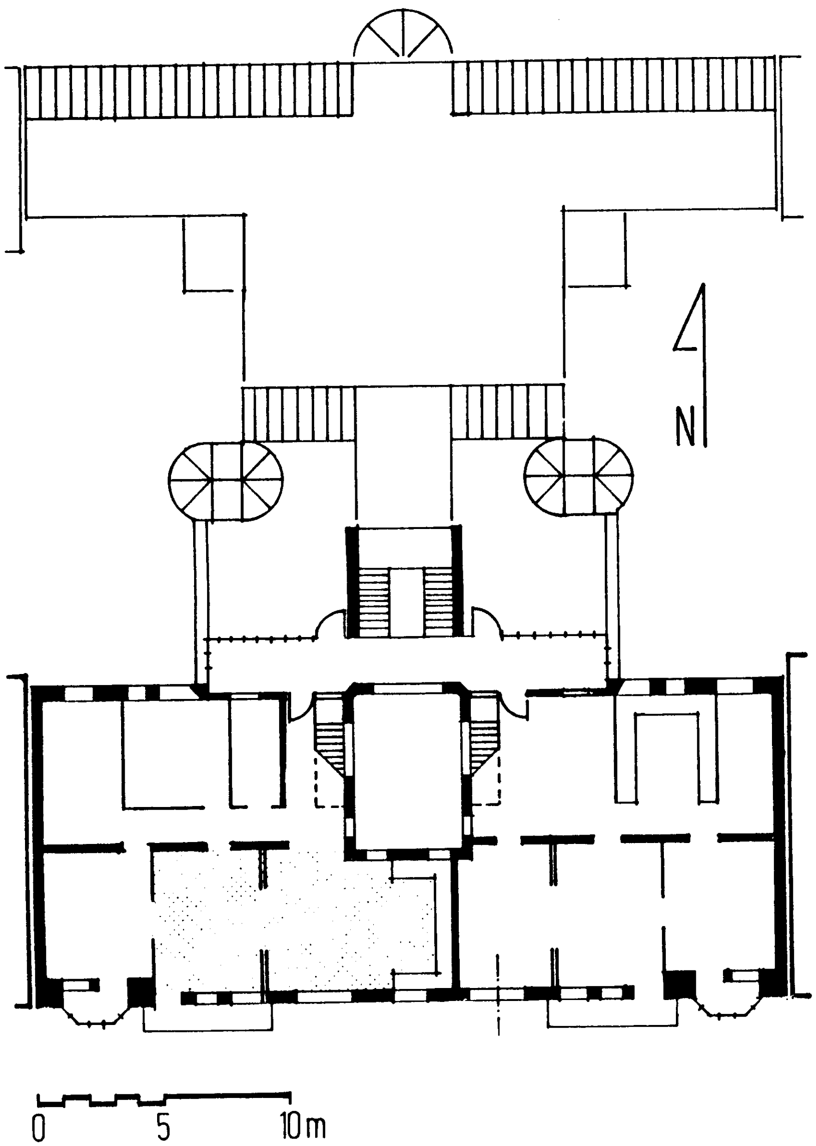
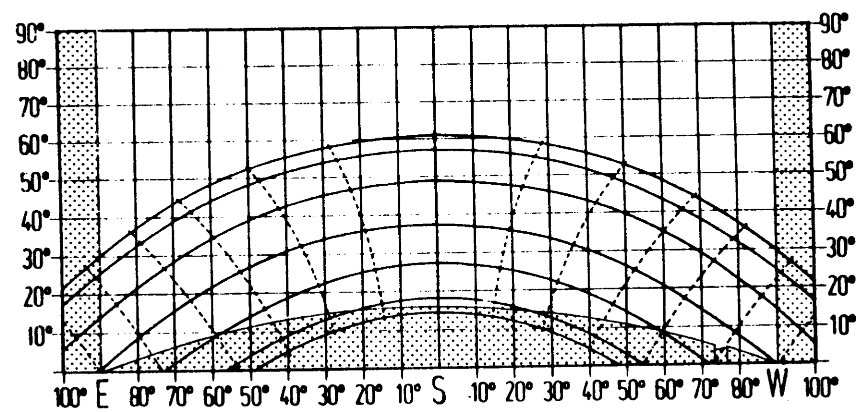
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°


N
0
5
10m


90°
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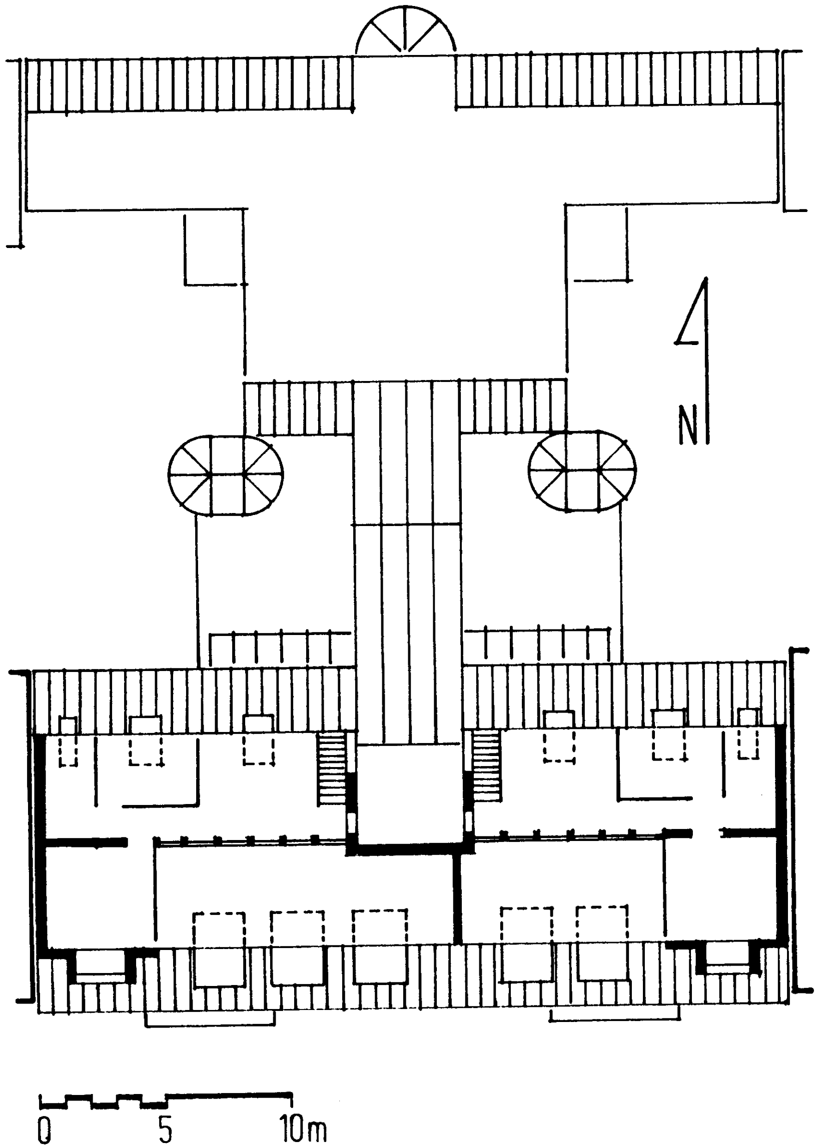
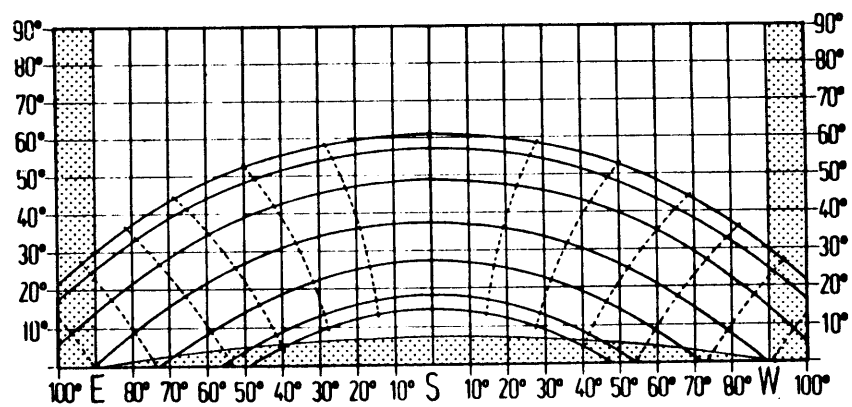
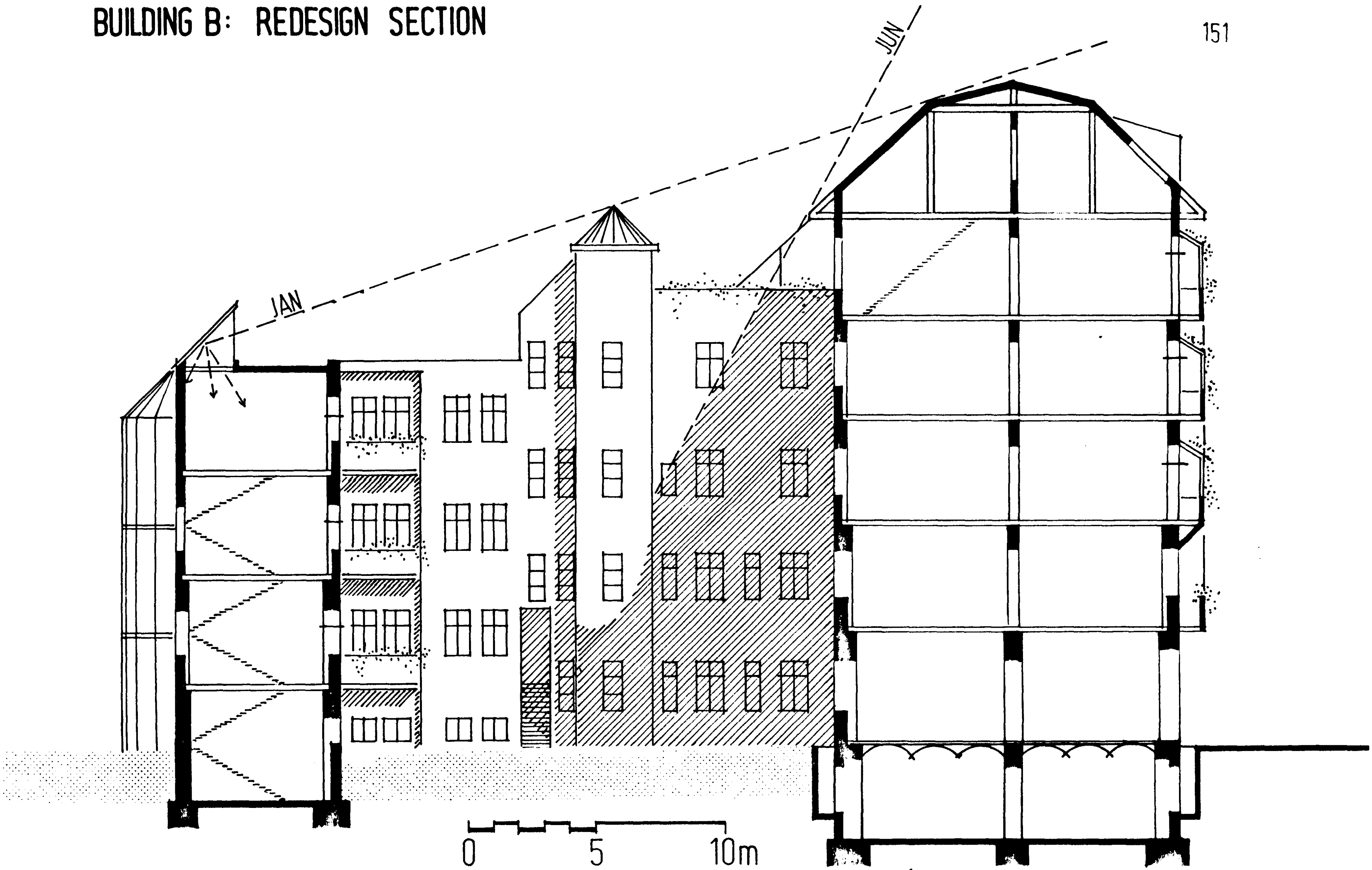
100° E 80° 70° 60° 50° 40° 30° 20° 10° S 10° 20° 30° 40° 50° 60° 70° 80° W 100°

BUILDING B : REDESIGN 6.FLOOR

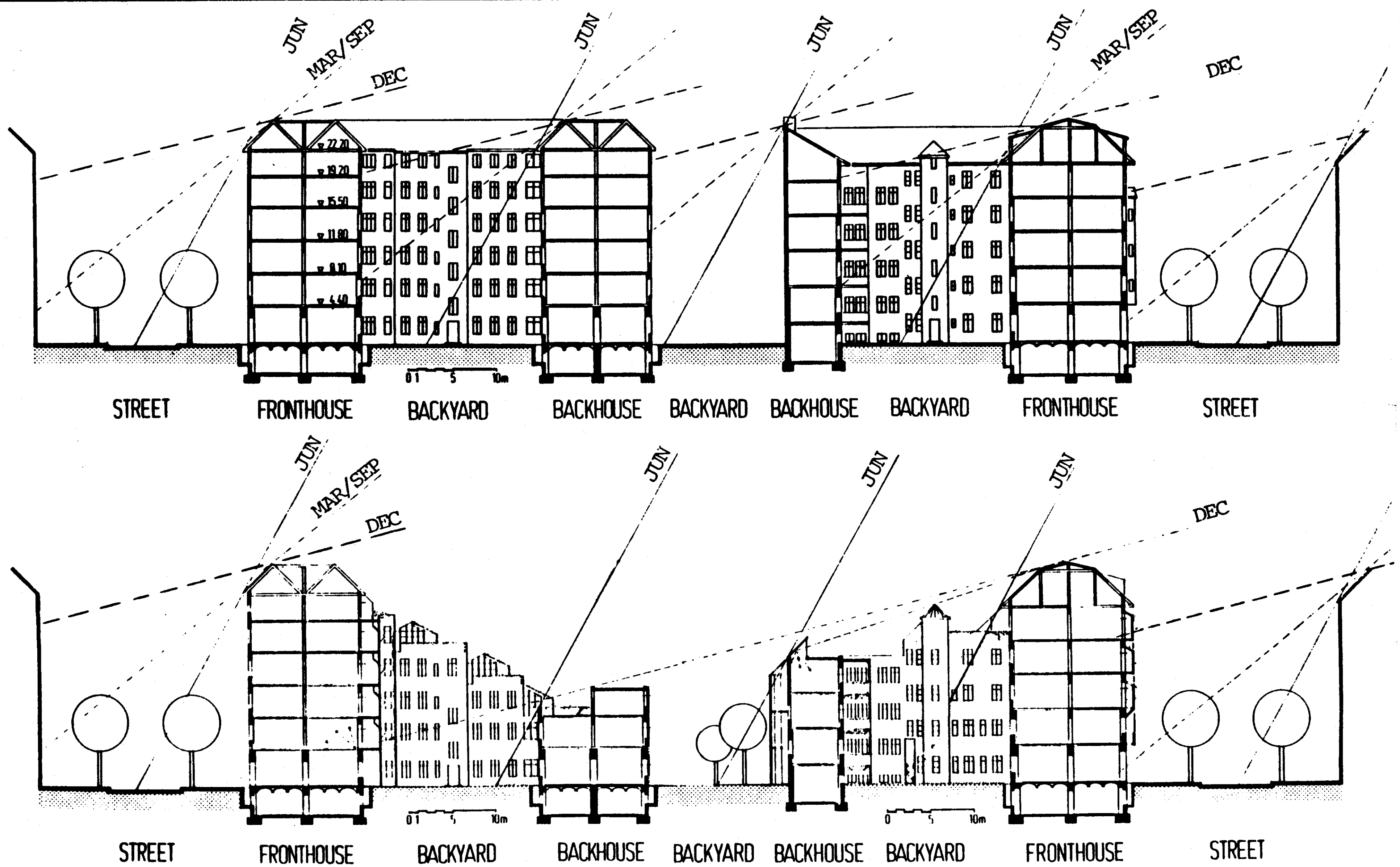


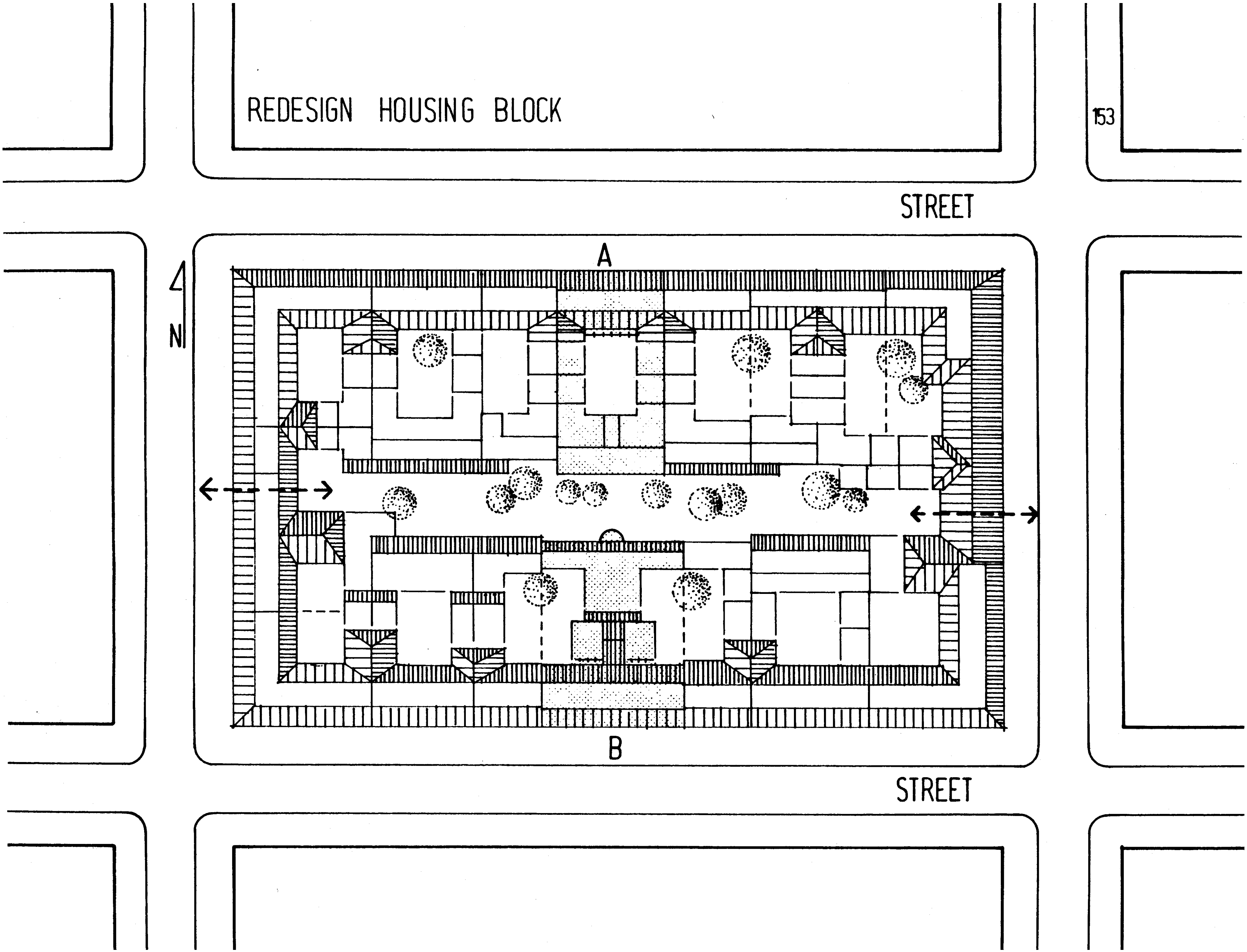


BUILDING B: REDESIGN SECTION



SECTION THROUGH COURTYARD BEFORE AND AFTER REDESIGN

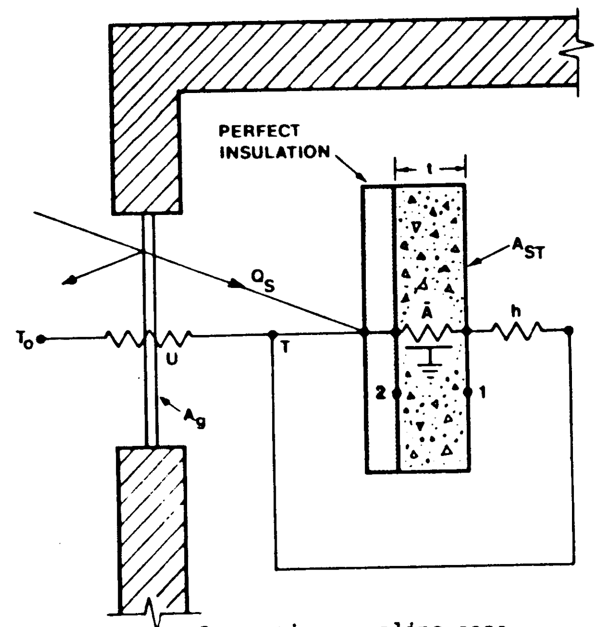



REDESIGN HOUSING BLOCK
STREET
A
N
B
STREET

Estimating Temperature Swings

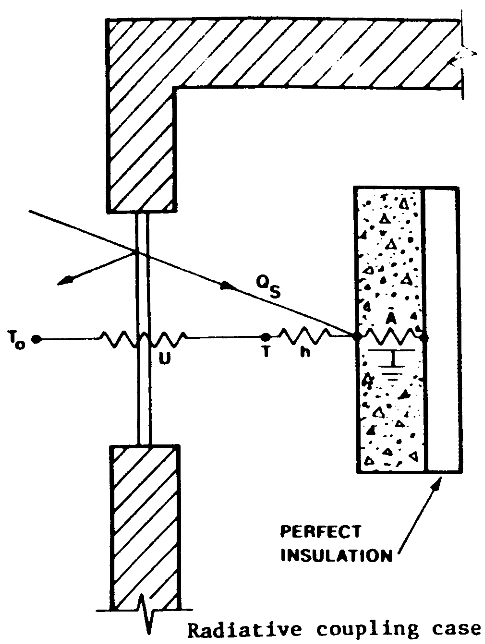
During the final phase of design, it is desirable to do a detailed estimate of each apartment's indoor air temperature swing in cases where this may be a problem. A designer who can predict the maximum interior temperatures of a direct gain space will be able to manipulate design elements such as area of south glazing, percentage of shading and thermal mass in order to achieve optimal thermal comfort conditions. By using direct gain approach in multifamily houses with low heat-losses through the building skin and low infiltration rates, the inside temperature swing in the building can be fairly large. Adequate thermal mass has to be provided in order to reduce uncomfortably high temperature swings.

A method developed by Philip W.B.Niles [51] is used to calculate the indoor temperatures of newly designed direct gain spaces. During years after the first publication several refinements were added to it by MIT-students: Stephen Hale wrote a TI-59 printer version of the method to speed up the calculation procedure.[47] James Rosen extended the method to make it applicable to a larger variety of buildings and construction types. [52] For the calculations in this thesis the TI-59 printer version is used in conjunction with a table from James Rosen's paper (see page 191). The program predicts maximum and minimum indoor temperatrues for directly passive heated spaces with an error of ± 1°C. The product is two sets of temperature swings: The first is typical of a configuration where the heat transfer of solar



Convective coupling case

energy to storage mass is dominated by convective exchange (the sun heats the mass storage via convection). The second is where heat transfer is dominated by radiative exchange (the sun heats the mass directly or via reflection).



Radiative coupling case

The program is limited to model only vertical south-facing solar glazing like the ones developed in this design problem.

The following information are needed to conduct the overheating calculations:

Fig. 63 Average daily temperature swings for Berlin-Dahlem [22]

mean daily temperature	Jan	Feb	Mar	Apr	May	Jun
maximum (°C)	1.9	3.1	7.8	13.4	18.7	21.8
minimum (°C)	-3.1	-2.9	-0.2	3.8	8.0	11.0
swing (°C)	5.0	5.0	8.0	9.6	10.7	10.8
	Jul	Aug	Sep	Oct	Nov	Dec
maximum (°C)	23.5	22.7	19.3	13.1	6.7	3.0
minimum (°C)	13.2	12.5	9.4	5.4	1.7	-1.5
swing (°C)	10.2	10.2	9.9	7.7	5.0	4.5

Fig. 64 Average daily clear day insulation on a vertical south-facing surface for Berlin-Dahlem in Wh/m^2 (from Appendix B):

Jan	Feb	Mar	Apr	May	Jun
3615	4803	5069	4465	3928	3720
Jul	Aug	Sep	Oct	Nov	Dec
3853	4300	4788	4563	3237	2956

These are irradiation values on an unobstructed, vertical southfacing surface. Under these conditions the surface intercepts the highest insulation values in March. Therefore March should be used for overheating calculations.
In case of obstructions (see Chapter 3) there might be another month which has the highest insolation values of all months. This month would then be the basis for an overheating calculation.

Fig. 65 ASHRAE Chapter 22.11

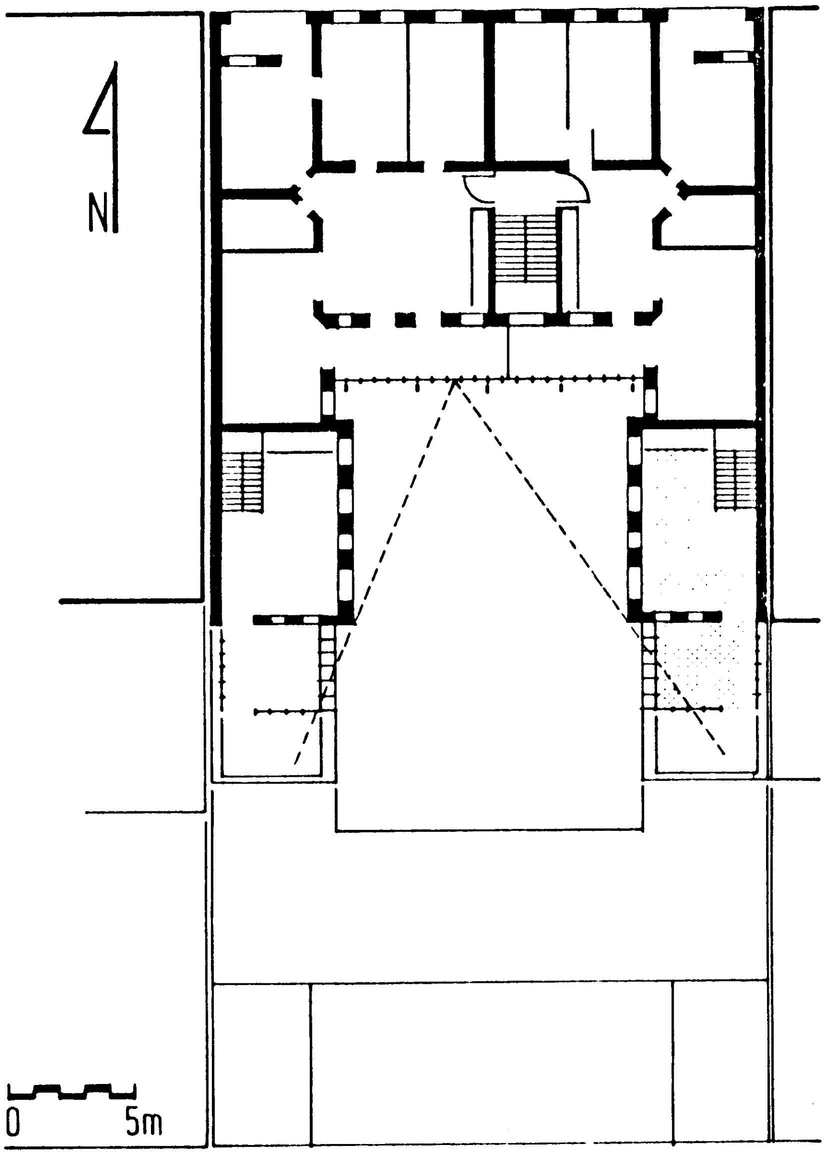
SECTION A. Surface Conductances

Position of Surface	Direction of Heat Flow	Surface Emittance: Non-reflective $\varepsilon = 0.90$	Reflective $\varepsilon = 0.20$	Reflective $\varepsilon = 0.05$
		h_i	h_i	h_i
STILL AIR				
Horizontal	Upward	1.63	0.91	0.76
Sloping—45 deg	Upward	1.60	0.88	0.73
Vertical........	Horizontal	1.46	0.74	0.59
Sloping—45 deg	Downward	1.32	0.60	0.45
Horizontal	Downward	1.08	0.37	0.22

Fig. 58

Material properties		Concrete	Limestone/Rock	Brick	Pine Wood	Dry Sand	Adobe	Gypsum Board	Water	Sheet Rock
Density	(lb/ft^3)	143	153	112	31	95	120	50	62.4	50
Specific heat	(Btu/lb°F)	0.21	0.22	0.22	0.67	0.19	0.20	0.26	1.0	0.20
Heat capacity	($Btu/ft^3 °F$)	30.0	33.7	24.6	20.8	18.0	24.0	13.0	62.4	10.0
Thermal conductivity	(Btu/ft°Fhr)	1.00	0.54	0.40	0.10	0.19	0.33	0.09	-	0.09
Radiantly coupled mass		Diurnal heat capacity ($Btu/ft^2 °F$)								
Thickness in inches:	1"	2.50	2.80	2.05	1.71	1.50	2.00	0.84	5.19	0.84
	2"	4.99	5.52	4.04	2.96	2.90	3.92	1.60	10.4	1.64
	3"	7.37	7.81	5.73	3.14	3.86	5.44	2.04	15.6	2.04
	4"	9.47	9.17	6.74	2.93	4.14	6.20	2.11	20.8	2.11
	6"	11.9	9.30	6.86	2.76	3.82	6.05	1.92	31.1	1.92
	8"	12.1	8.63	6.36	2.77	3.62	5.62	1.84	41.7	1.80
	12"	11.0	8.29	6.10	2.77	3.61	5.49	1.85	62.4	1.80
	16"	10.6	8.33	6.13	2.77	3.62	5.52	1.85	83.3	1.80

During the design process several runs were conducted to alter and modify the final design. Finally, for each type of direct gain space, the corresponding temperature swings (convectively and radiatively coupled) were determinated and are presented on the following pages.
The results show that the existing massive construction of the old brick-houses provides enough thermal storage mass to absorb the irradiated solar energy and thereby keep the average indoor temperature swings within comfort levels.



Building skin losses:

Room:	gross wall area	: 37. m^2
	minus window area	: 7 m^2 x 1.4 = 9.8 W
	net wall area	: 30.24 m^2 x 0.5 = 15.12 W
Roof area		: 15.64 m^2 x 0.4 = 6.25 W
Sunspace:	wall area	: 13.2 m^2 x 0.7 = 9.24 W
	E + W windows	: 11.2 m^2 x 1.4 = 15.68
	roof area	: 6.6 m^2 x 1.4 = 9.24
Southfacing glass area		: 21.56 m^2 – 15% = 18.33 m^2
Volume:	room	: 114,04 m^3
	sunspace	: 43.56 m^3

Storage surface area

Room:	wall area	: 71.64 m^2 → 6.86 (2" BRICK)
	ceiling area	: 31.68 m^2 → 2.5 (1" HEAVY PL)
	floor area	: 31.68 m^2 → 1.71 (1" WOOD)
Sunspace:	wall area	: 5.6 m^2 → 6.86 (2" BRICK)
	floor area	: 15 m^2 → 22,5 (
		Σ 155,6 m^2 → avg. 6.42

Overheating calculation : BUILDING A – REDESIGN 4.FLOOR

STO	Description	Metric units	Con.-factor	English units
01	(Optional to determine south glazing area:) indoor design temperature to be maintained :	°C	x 1.8 + 32	°F
02	Average outdoor air temperature over a 24 hr period :	3.7 °C	x 1.8 + 32	38.7 °F
	Total hourly house-losses: building-skin-losses m^2 x W/°C m^2 =	86.89 W		
	plus infiltration-losses 157.6 m^3 x 0.34 W/°C m^3 x 0.5 AC/hr =	+ 26.8 W		
	minus UA south glazing 21.56 m^2 x 1.0 W/°C m^2 =	- 21.56 W		
03	total :	92.13 W	x 3.412	314.3 Btu/hr
	Daily clear day insolation intercepted per qm of vertical south-glazing (from fig. 64) :	5069 Wh/m^2		
	per hour :	: 24 hrs		
	times av. transmission of glazing :	211 x 0.62		
04	Total received inside building :	130.82 W/m^2	x 0.31606	41.43 Btu/ft^2hr
05	k-value of south glazing area :	1 W/m^2K	x 0.17612	0.17612 Btu/ft^2hr°F
	Average outdoor air temperature-swing (from fig. 63) divided by 2 :	8 °C : 2		
06	total :	4 °C	x 1.8	7.2 °F
	Storage surface area : divided by south glass area :	155.6 m^2 : 18.33 m^2		
07	ratio :	8.48		8.48
08	Surface conductance of storage-material (from fig. 65) :	W/m^2K	x 0.17612	1 Btu/ft^2hr°F
09	Period of daily temperature-swing :	24 hrs		24 hrs
	Storage mass heat capacity (fig. 58) : per thickness specified :	Wh/m^3K m		
10	total :	Wh/m^2K	x 0.17612	6.42 Btu/ft^2°F
11	(Optional to determine indoor design temperature:) area of south glazing :	18.33 m^2	x 10.764	197.30 ft^2
48	Average hourly internal gains :	400 W	x 3.412	1364.8 Btu/hr

List input-data:

0.	01
38.7	02
314.3	03
41.34	04
0.17612	05
7.2	06
8.48	07
1.	08
24.	09
6.42	10
197.3	11

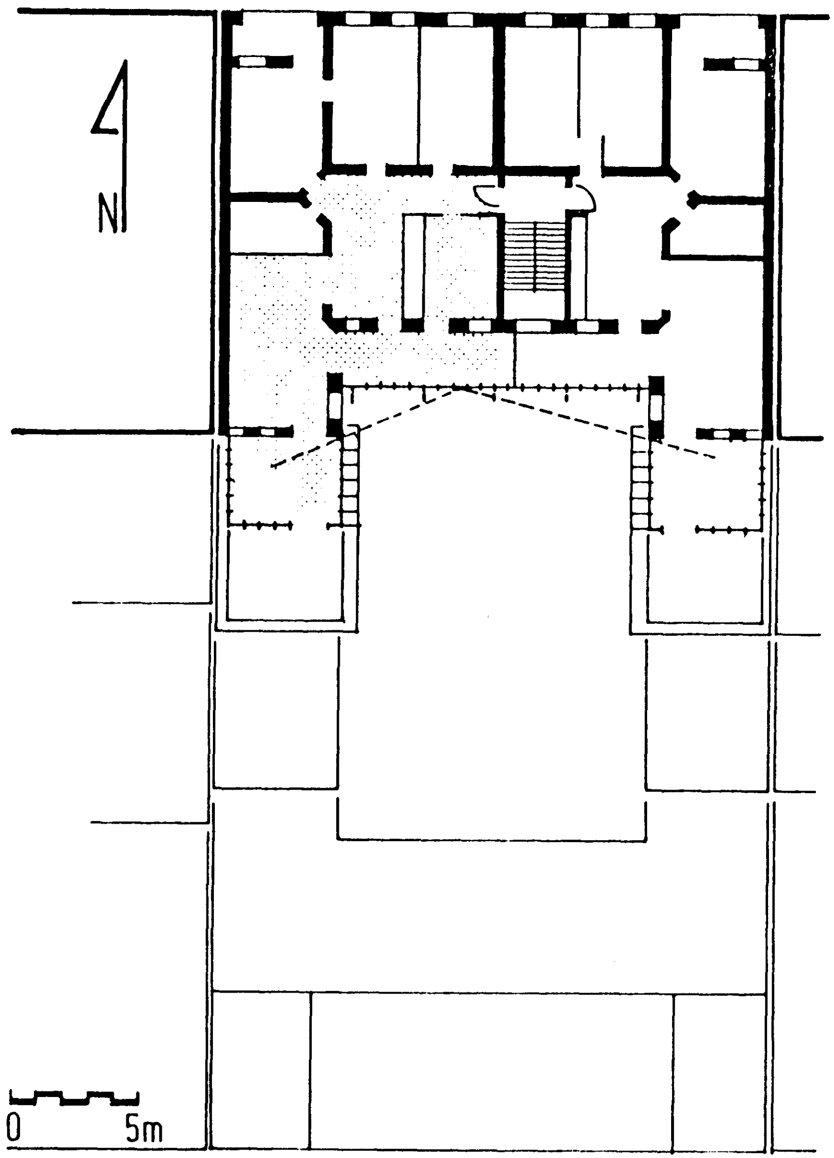
Half indoor temp. swings:

11.90867426	CONV
5.207626109	RAD

Indoor temperature and range of temperature swings:

65.97753494	°F
54.06886068	TO
77.8862092	
60.76990883	TO
71.18516105	

BUILDING A: REDESIGN 5.FLOOR



Building skin losses:

Room: gross wall area : $7.4\ m^2$
minus window area : $2\ m^2 \times 1.4 = 2.8$ W
net wall area : $5.4\ m^2 \times 0.7 = 3.78$ W

Roof area : $8\ m^2 \times 0.4 = 3.2$ W

Sunspace: wall area : $18.8\ m^2 \times 0.7 = 13.16$ W
E + W windows : $11.2\ m^2 \times 1.4 = 15.68$ W
roof area : $10.12\ m^2 \times 1.6 = 16.2$ W

Southfacing glass area : $36.94\ m^2 - 15\% = 31.4\ m^2$

Volume: room : $237.3\ m^3$
sunspace : $90.11\ m^3$

Storage surface area

Room: wall area : $67.7\ m^2 \rightarrow 6.86$ (6" BRICK)
$33.25\ m^2 \rightarrow 4.04$ (3" BRICK)
ceiling area : $67.8\ m^2 \rightarrow 2.50$ (1" HEAVY PL)
floor area : $67.8\ m^2 \rightarrow 1.71$ (1" WOOD)
Sunspace: wall area : $5.6\ m^2 \rightarrow 6.86$ (6" BRICK)
floor area : $15\ m^2 \rightarrow 1.71$ (1" WOOD)
$28\ m^2 \rightarrow 7.37$ (3" CONCRETE)
$\Sigma\ 285{,}15 \rightarrow$ avg. 4.05 BTU/ft²

Overheating calculation : BUILDING A – REDESIGN 5.FLOOR

STO	Description	Metric units	Con.-factor	English units
01	(Optional to determine south glazing area:) indoor design temperature to be maintained :	°C	x 1.8 + 32	°F
02	Average outdoor air temperature over a 24 hr period :	3.7 °C	x 1.8 + 32	38.7 °F
	Total hourly house-losses: building-skin-losses m^2 x W/°C m^2 =	113.92 W		
	plus infiltration-losses 327.4 m^3 x 0.34 W/°C m^3 x 0.5 AC/hr =	+ 55.65 W		
	minus UA south glazing 36.94 m^2 x 1.6 W/°C m^2 =	- 59.10 W		
03	total :	110.47 W	x 3.412	376.93 Btu/hr
	Daily clear day insolation intercepted per qm of vertical south-glazing (from fig. 64) :	MARCH 4866 Wh/m^2		
	per hour :	: 24 hrs		
	times av. transmission of glazing :	202.75 x 0.62		
04	Total received inside building :	125.70 W/m^2	x 0.31606	39.73 Btu/ft^2hr
05	k-value of south glazing area :	1.6 W/m^2K	x 0.17612	0.2817 Btu/ft^2hr°F
	Average outdoor air temperature-swing (from fig. 63) divided by 2 :	8 °C : 2		
06	total :	4 °C	x 1.8	7.2 °F
	Storage surface area : divided by south glass area :	285.15 m^2 : 31.4 m^2		
07	ratio :	9.08		9.08
08	Surface conductance of storage-material (from fig. 65) :	W/m^2K	x 0.17612	1 Btu/ft^2hr°F
09	Period of daily temperature-swing :	24 hrs		24 hrs
	Storage mass heat capacity (fig. 58) : per thickness specified :	Wh/m^3K m		
10	total :	Wh/m^2K	x 0.17612	4.05 Btu/ft^2°F
11	(Optional to determine indoor design temperature:) area of south glazing :	31.4 m^2	x 10.764	337.98 ft^2
48	Average hourly internal gains :	400 W	x 3.412	1364.8 Btu/hr

List input-data:

0.	01
38.7	02
376.93	03
39.73	04
0.2817	05
7.2	06
9.08	07
1.	08
24.	09
4.05	10
337.98	11

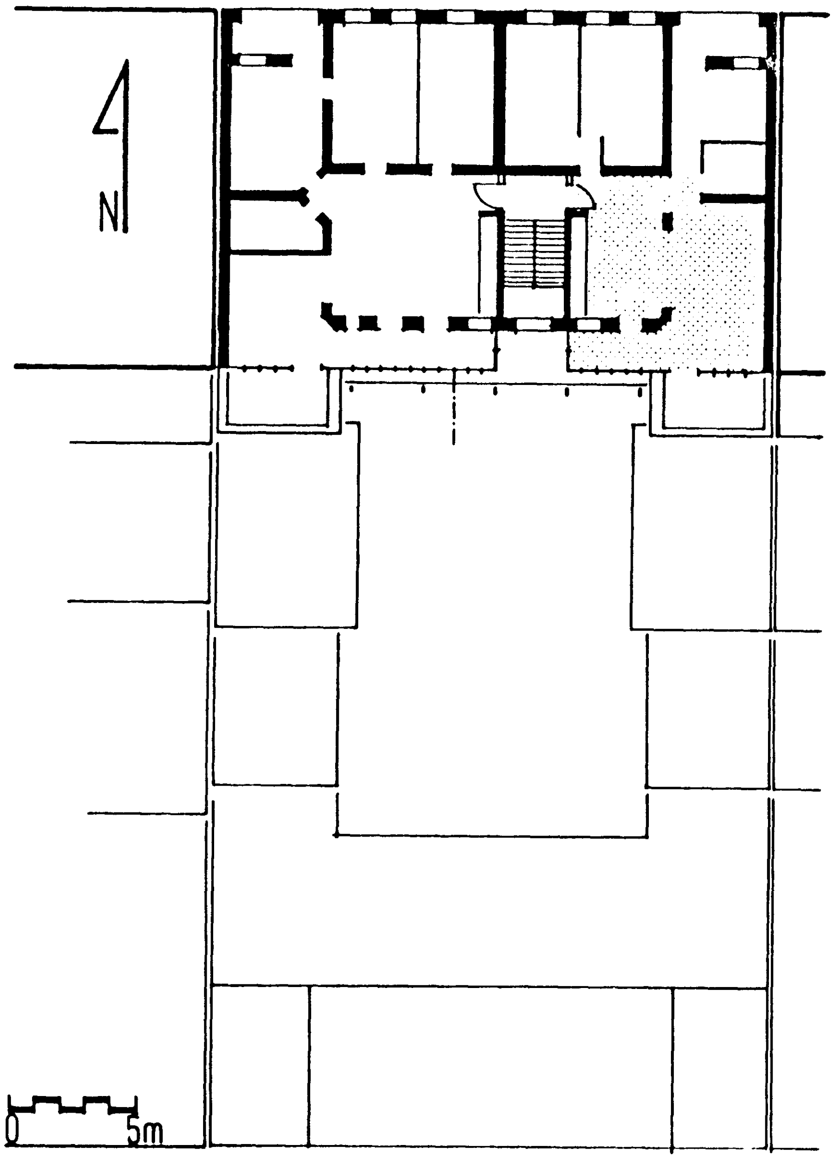
Half indoor temp. swings:

10.83868804	CONV
6.739530395	RAD

Indoor temperature and range of temperature swings:

70.03133773	°F
59.19264969	TO
80.87002577	
63.29180734,	TO
76.77086813	

BUILDING A: REDESIGN 6.FLOOR



Building skin losses:

Room: gross wall area :

minus window area :

net wall area :

Roof area :

Sunspace: wall area : $2{,}8\,m^2 \times 0.7 = 1.96\,W$

E + W windows : $3.78\,m^2 \times 1.4 = 5.29\,W$

roof area : $9.6\,m^2 \times 1.6 = 15.36\,W$

Southfacing glass area : $16.8\,m^2 - 15\% = 14{,}3\,m^2$

Volume: room : 129.92

sunspace : 31.36

Storage surface area

Room: wall area : $6888\,m^2$ → 6.86 (6" BRICK)

ceiling area : $46.4\,m^2$ → 2,50 (1" HEAVY PL.)

floor area : $46.4\,m^2$ → 1.71 (1" WOOD)

Sunspace: wall area :

floor area : $11.2\,m^2$ → 7,37 (3" CONCRETE)

$\Sigma\ 172{,}88\,m^2$ → avg. 4.34

Overheating calculation : BUILDING A - REDESIGN 6.FLOOR

STO	Description	Metric units	Con.-factor	English units
01	(Optional to determine south glazing area:) indoor design temperature to be maintained :	°C	x 1.8 + 32	°F
02	Average outdoor air temperature over a 24 hr period :	3.7 °C	x 1.8 + 32	38.7 °F
	Total hourly house-losses: building-skin-losses m^2 x W/°C m^2 =	67.65 W		
	plus infiltration-losses 161.2 m^3 x 0.34 W/°C m^3 x 0.5 AC/hr =	+ 27.4 W		
	minus UA south glazing 16.3 m^2 x 1.6 W/°C m^2 =	- 26.88 W		
03	total :	68.17 W	x 3.412	232.5 Btu/hr
	Daily clear day insolation intercepted per qm of vertical south-glazing (from fig. 64) : per hour : times av. transmission of glazing :	5069 Wh/m^2 : 24 hrs 211 x 0.62		
04	Total received inside building :	130.82 W/m^2	x 0.31606	41.3 Btu/ft^2hr
05	k-value of south glazing area :	1.6 W/m^2K	x 0.17612	0.2817 Btu/ft^2hr°F
	Average outdoor air temperature-swing (from fig. 63) divided by 2 :	8 °C : 2		
06	total :	4 °c	x 1.8	7.2 °F
	Storage surface area : divided by south glass area :	172.9 m^2 : 14.3 m^2		
07	ratio :	12.09		12.09
08	Surface conductance of storage-material (from fig. 65) :	W/m^2K	x 0.17612	1 Btu/ft^2hr°F
09	Period of daily temperature-swing :	24 hrs		24 hrs
	Storage mass heat capacity (fig. 58) : per thickness specified :	Wh/m^3K m		
10	total :	Wh/m^2K	x 0.17612	4.34 Btu/ft^2°F
11	(Optional to determine indoor design temperature:) area of south glazing :	14.3 m^2	x 10.764	153.92 ft^2
48	Average hourly internal gains :	400 W	x 3.412	1364.8 Btu/hr

List input-data:

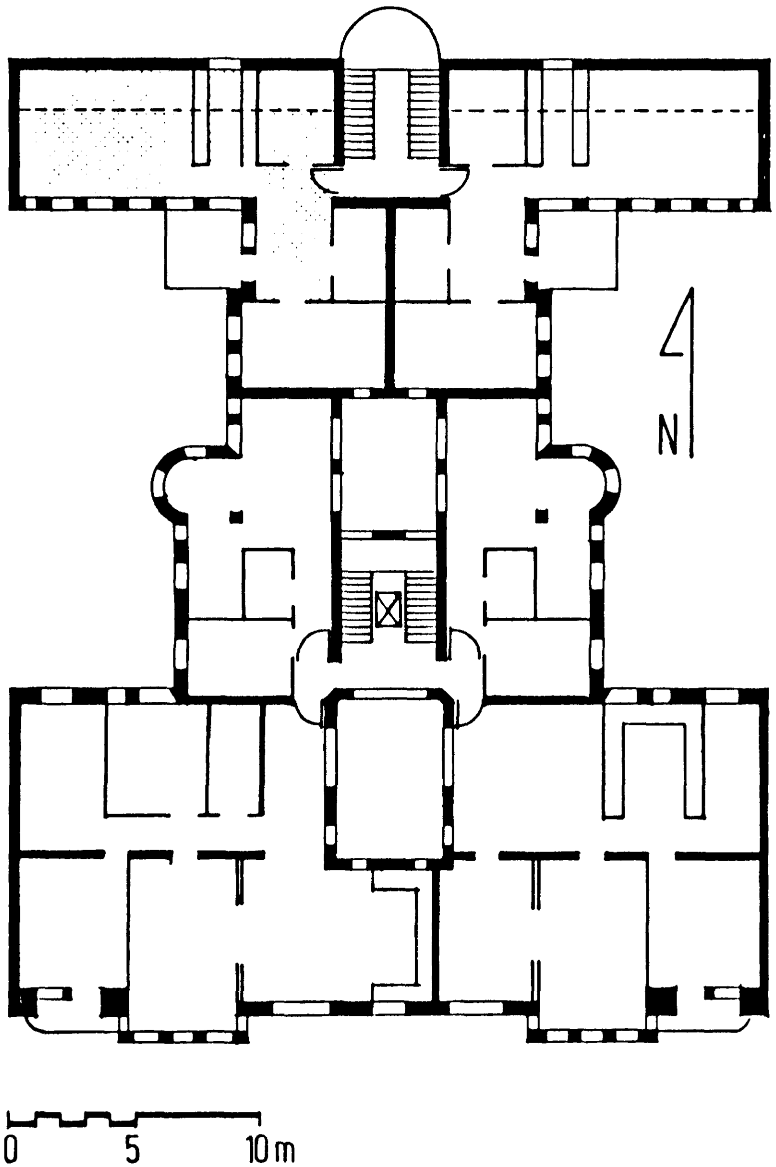
0.	01
38.7	02
232.5	03
41.34	04
0.2817	05
7.2	06
12.09	07
1.	08
24.	09
4.34	10
153.92	11

Half indoor temp. swings:

10.18505765	CONV
6.055034551	RAD

Indoor temperature and range of temperature swings:

66.71375124	°F
56.52869359	TO
76.8988089	
60.65871669	TO
72.76878579	



Building skin losses:

Room: gross wall area	: 87,4 m^2		
minus window area	: 8,0 m^2 × 1.4	=	11.2 W
net wall area	: 79,4 m^2 × 0.5	=	39.7 W
Roof area	: 62.5 m^2 × 0.2	=	12.5. W
Sunspace: wall area	:		
E + W windows	:		
roof area	:		
Southfacing glass area	: 31 m^2 - 15% = 26.4 m^2		
Volume: room	: 300,65 m^3		
sunspace	:		

Storage surface area

Room: wall area	: 107 m^2 → 6.86 (6" BRICK)
ceiling area	: 62.5 m^2 → 2,5 (1" HEAVY PLASTER)
floor area	: 62,5 m^2 → 1.71 (1" WOOD)
PARTITION wall area	: 59.2 m^2 → 4.09 (2" BRICK)
floor area	:
	Σ 291.2 m^2 → avg. 4.25 BTU/ft^2

Overheating calculation: BUILDING B - REDESIGN 3.FLOOR

STO	Description	Metric units	Con.-factor	English units
01	(Optional to determine south glazing area:) indoor design temperature to be maintained :	°C	x 1.8 + 32	°F
02	Average outdoor air temperature over a 24 hr period :	3,7 °C	x 1.8 + 32	38.7 °F
	Total hourly house-losses: building-skin-losses m^2 x W/°C m^2 =	113 W		
	plus infiltration-losses 300.65 m^3 x 0.34 W/°C m^3 x 0.5 AC/hr =	+51.1 W		
	minus UA south glazing 31 m^2 x 1.6 W/°C m^2 =	- 49.6 W		
03	total :	114.5 W	x 3.412	390.67 Btu/hr
	Daily clear day insolation intercepted per qm of vertical south-glazing (from fig. 64) :	5069 Wh/m^2		
	per hour :	: 24 hrs		
	times av. transmission of glazing :	211 x 0.62		
04	Total received inside building :	130.82 W/m^2	x 0.31606	41.34 Btu/ft^2hr
05	k-value of south glazing area :	1.6 W/m^2K	x 0.17612	0.281792 Btu/ft^2hr°F
	Average outdoor air temperature-swing (from fig. 63) divided by 2 :	8 °C : 2		
06	total :	4 °C	x 1.8	7.2 °F
	Storage surface area :	2912 m^2		
	divided by south glass area :	: 26.4 m^2		
07	ratio :	11.03		11.03
08	Surface conductance of storage-material (from fig. 65) :	W/m^2K	x 0.17612	1 Btu/ft^2hr°F
09	Period of daily temperature-swing :	24 hrs		24 hrs
	Storage mass heat capacity (fig. 58) :	Wh/m^3K		
	per thickness specified :	m		
10	total :	Wh/m^2K	x 0.17612	4.25 Btu/ft^2°F
11	(Optional to determine indoor design temperature:) area of south glazing :	m^2	x 10.764	284.16 ft^2
48	Average hourly internal gains :	400 W	x 3.412	1364.8 Btu/hr

List input-data:

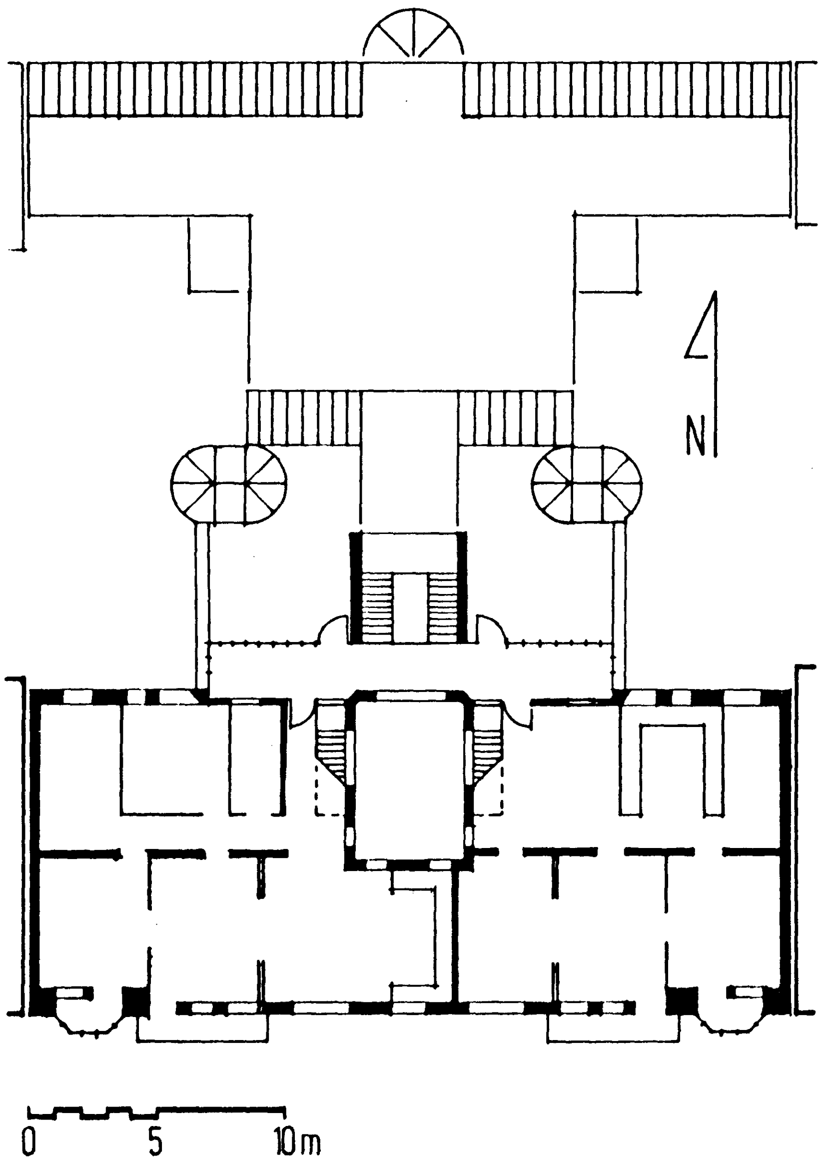
0.	01
38.7	02
390.67	03
41.34	04
0.2817	05
7.2	06
11.03	07
1.	08
24.	09
4.25	10
284.16	11

Half indoor temp. swings:

10.39250325	CONV
6.264884873	RAD

Indoor temperature and range of temperature swings:

66.55527209	°F
56.16276883	TO
76.94777534	
60.29038721	TO
72.82015696	



Building skin losses:

Room: gross wall area :
minus window area :
net wall area : $35.6 m^2 \times 0.7 =$ 24.92 W

Roof area : $92 m^2 \times 0.4 =$ 36.8 W

Sunspace: wall area :
E + W windows :
roof area :

Southfacing glass area : $40 m^2 - 15\% = 34 m^2$

Volume: room : $460 m^3$
sunspace :

Storage surface area

Room: wall area : $191.5 m^2 \rightarrow 6.86$ (6" BRICK)
ceiling area :
floor area : $66 m^2 \rightarrow 1.71$ (1" WOOD)

Sunspace: wall area :
floor area :

$\Sigma\ 257.5 m^2 \rightarrow$ avg. 5.53

Overheating calculation: BUILDING B - REDESIGN 5.FLOOR

STO	Description	Metric units	Con.-factor	English units
01	(Optional to determine south glazing area:) indoor design temperature to be maintained :	°C	x 1.8 + 32	°F
02	Average outdoor air temperature over a 24 hr period :	3.7 °C	x 1.8 + 32	38.7 °F
	Total hourly house-losses: building-skin-losses m^2 x W/°C m^2 =	125.7 W		
	plus infiltration-losses 460 m^3 x 0.34 W/°C m^3 x 0.5 AC/hr =	+ 78.2 W		
	minus UA south glazing 40 m^2 x 1.6 W/°C m^2 =	- 64 W		
03	total :	139.9 W	x 3.412	477.3 Btu/hr
	Daily clear day insolation intercepted per qm of vertical south-glazing (from fig. 64) :	5069 Wh/m^2		
	per hour :	: 24 hrs		
	times av. transmission of glazing :	211 x 0.62		
04	Total received inside building :	130.82 W/m^2	x 0.31606	41.34 Btu/ft^2hr
05	k-value of south glazing area :	1.6 W/m^2K	x 0.17612	0.2817 Btu/ft^2hr°F
	Average outdoor air temperature-swing (from fig. 63) divided by 2 :	8 °C : 2		
06	total :	4 °C	x 1.8	7.2 °F
	Storage surface area :	257.5 m^2		
	divided by south glass area :	: 34 m^2		
07	ratio :	7.57		7.57
08	Surface conductance of storage-material (from fig. 65) :	W/m^2K	x 0.17612	1 Btu/ft^2hr°F
09	Period of daily temperature-swing :	24 hrs		24 hrs
	Storage mass heat capacity (fig. 58) :	Wh/m^3K		
	per thickness specified :	m		
10	total :	Wh/m^2K	x 0.17612	5.53 Btu/ft^2°F
11	(Optional to determine indoor design temperature:) area of south glazing :	34 m^2	x 10.764	365.97 ft^2
48	Average hourly internal gains :	400 W	x 3.412	1364.8 Btu/hr

List input-data:

0.	01
38.7	02
477.3	03
41.34	04
0.2817	05
7.2	06
7.57	07
1.	08
24.	09
5.53	10
365.97	11

Half indoor temp. swings:

12.45827229	CONV
6.188243247	RAD

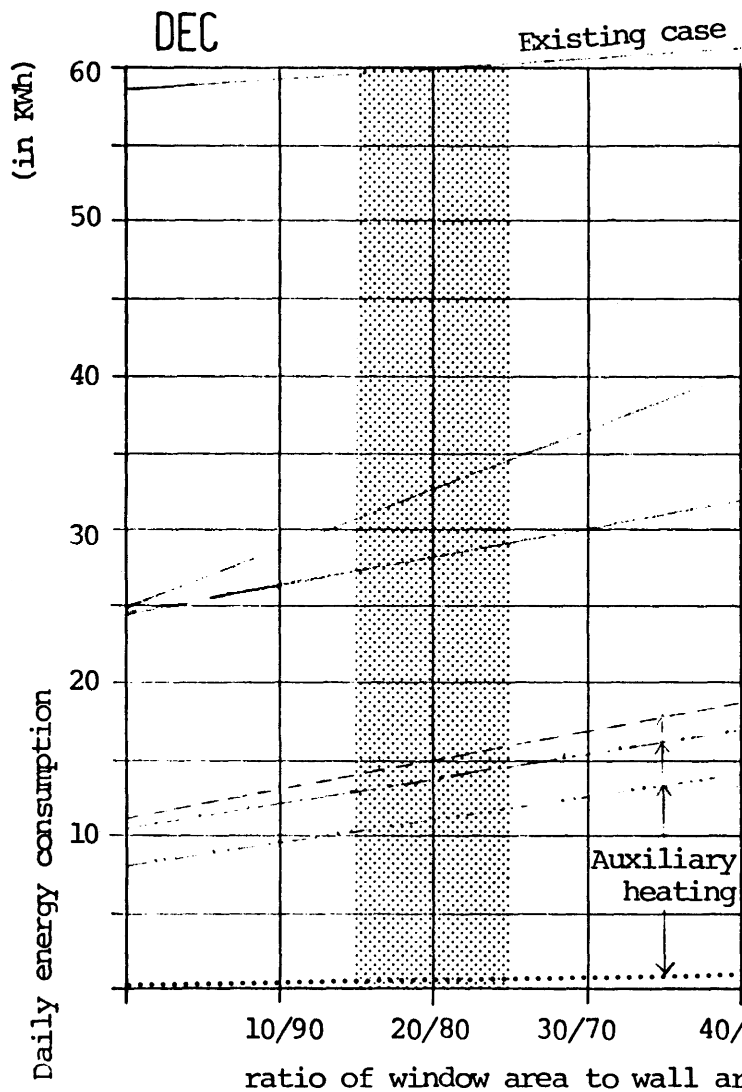
Indoor temperature and range of temperature swings:

67.11863791	°F
54.66036562	TO
79.5769102	
60.93039467	TO
73.30688116	

Calculations of Heat Loss and Solar Gain for North-facing Facades

Using new window finishing materials with a low k-value (1.6 W/°Cm^2) and a relatively high transmission-factor (65%) permits gaining solar energy even from the diffuse light available on north sides of buildings. The following calculation (described throughout Chapter 2 and Chapter 3) uses one apartment in the 6th floor of building A - see page 133 - to demonstrate the effects of various improvements including the new glass from S.I.V.
The existing situation is described by the following facts: 40m^2 exterior facade are divided into 30m^2 of massive wall area and 10m^2 of window area. (25% glass area is on the upper end of the usual range of 15%-25% for Berlin's tenement housing.) Only the ventilation losses of the northern half of the apartment are calculated because this is the main area which is affected by solar gains from the north side. The volume amounts to 190m^3 which leads to 64W/°c heat loss, assuming 1.0 air change per hour. The k-value of the existing wall is 2.11 W/°Cm^2, the k-value of the double glazing is 3.0 W/°Cm^2. Internal gains are assumed to be 10 KWh per day.
Similar apartment configurations but with varying percentages of glass area are quite common for Berlin. Therefore the following graphs are extended to both sides to provide results for a broader range of possible situations. It also might give some clues about the effects of enlarging window areas of backyard facades: do larger windows with new glazing materials reduce or increase net heat losses?

The upper solid line in the first graph (Fig.) shows the losses of the unchanged apartment on a day in December. Different kinds of dashed lines representdifferent stages of improvement described on the right hand side of the graph. The dotted line stands for the solar gains received through the northfacing window areas. All other graphs on the following pages show the same kind of improvement measures but for different months.



ratio of window area to wall area
(typical range for Berlin: 15-25%)

Existing case:

k-value of wall : 2.11 W/°Cm^2
k-value of window: 3.00 W/°Cm^2
infiltration-rate: 1.0/hr; no night insulation

1. Improvement, assuming:
k-value of wall : 0.50 W/°cm^2
(all other factors unchanged)

2. Improvement, assuming:
k-value of wall : 0.50 W/°Cm^2
k-value of window: 1.60 W/°Cm^2
(all other factors unchanged)

3. Improvement
Redesign base-case, assuming:

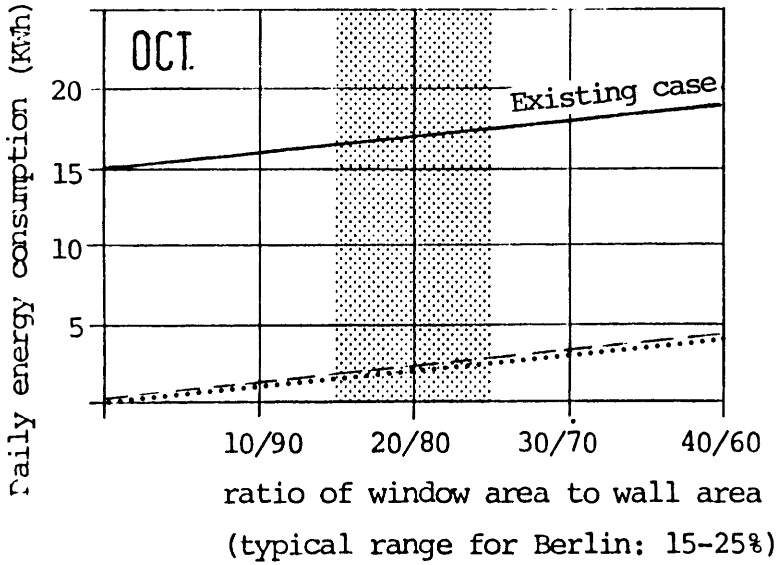
k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.6 W/°Cm^2
infiltration-rate: 0.5/hr; no night insulation

Redesign improved case, assuming:

k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.0 W/°Cm^2
infiltration-rate: 0.5/hr; with night insulation
heat-exchanger 50% HEAT RECOVERY

Heat gains, assuming:

60% total solar transmission through the glazing
90% absorption inside the building
178 W/m^2 daily irradiation on a vertical north-facing surface (DECEMBER)



---- Redesign base-case, assuming:

k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.6 W/°Cm^2
infiltration-rate: 0.5/hr; no night insulation

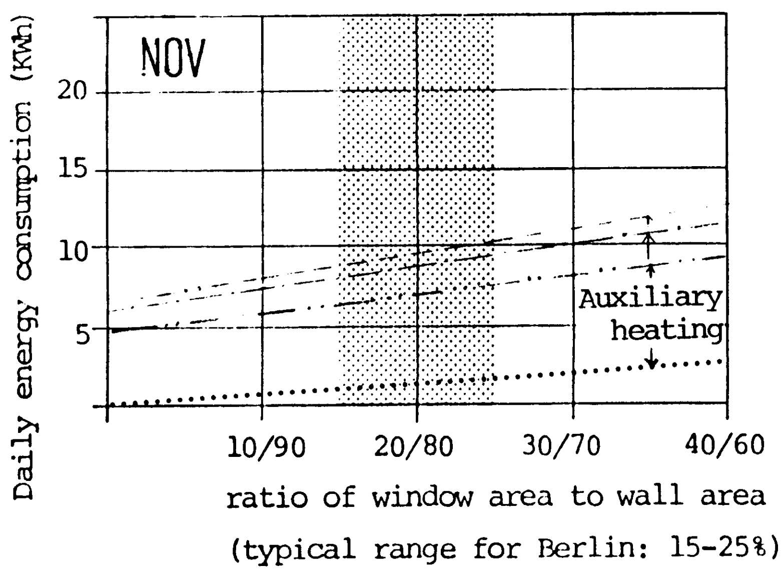
-·-·- Redesign improved case, assuming:

k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.0 W/°Cm^2
infiltration-rate: 0.5/hr; with night insulation

-··-·· heat-exchanger with 50% heat recovery

...... Heat gains, assuming:

60% total solar transmission through the glazing
90% absorption inside the building
432 W/m^2 daily irradiation on a vertical north-facing surface



---- Redesign base-case, assuming:

k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.6 W/°Cm^2
infiltration-rate: 0.5/hr; no night insulation

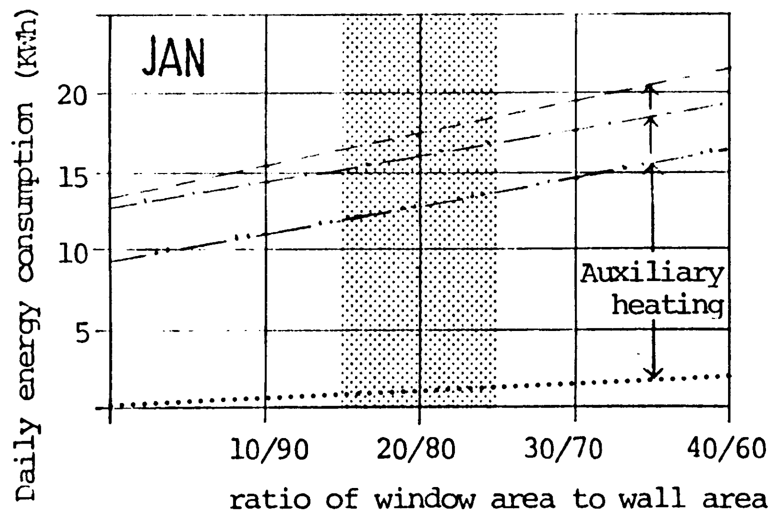
-·-·- Redesign improved case, assuming:

k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.0 W/°Cm^2
infiltration-rate: 0.5/hr; with night insulation

-··-·· heat-exchanger with 50% heat recovery

...... Heat gains, assuming:

60% total solar transmission through the glazing
90% absorption inside the building
271 W/m^2 daily irradiation on a vertical north-facing surface



ratio of window area to wall area
(typical range for Berlin: 15-25%)

---- Redesign base-case, assuming:

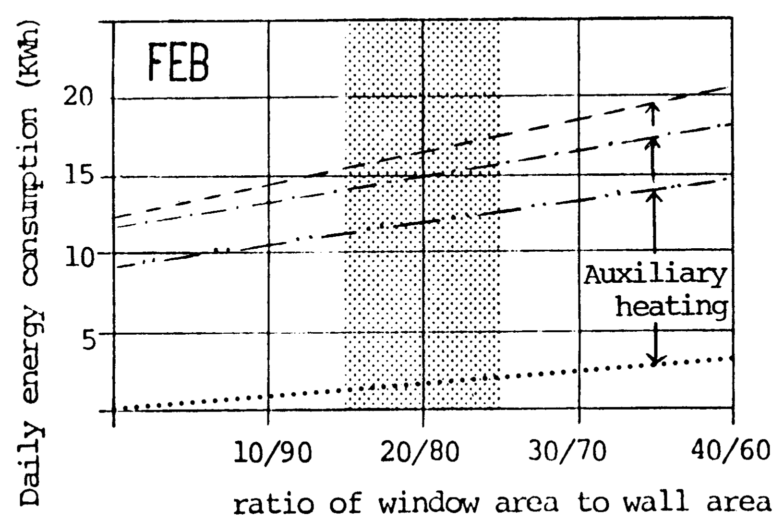
k-value of wall : 0.5 $W/°Cm^2$
k-value of window: 1.6 $W/°Cm^2$
infiltration-rate: 0.5/hr; no night insulation

-·-·- Redesign improved case, assuming:

k-value of wall : 0.5 $W/°Cm^2$
k-value of window: 1.0 $W/°Cm^2$
infiltration-rate: 0.5/hr; with night insulation
-·· heat-exchanger with 50% heat recovery

...... Heat gains, assuming:

60% total solar transmission through the glazing
90% absorption inside the building
237 W/m^2 daily irradiation on a vertical north-facing surface



ratio of window area to wall area
(typical range for Berlin: 15-25%)

---- Redesign base-case, assuming:

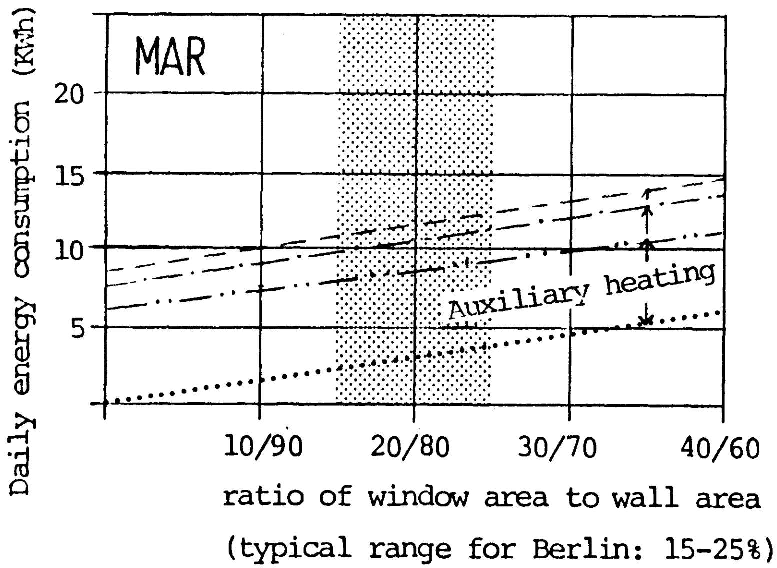
k-value of wall : 0.5 $W/°Cm^2$
k-value of window: 1.6 $W/°Cm^2$
infiltration-rate: 0.5/hr; no night insulation

-·-·- Redesign improved case, assuming:

k-value of wall : 0.5 $W/°Cm^2$
k-value of window: 1.0 $W/°Cm^2$
infiltration-rate: 0.5/hr; with night insulation
-·· heat-exchanger with 50% heat recovery

...... Heat gains, assuming:

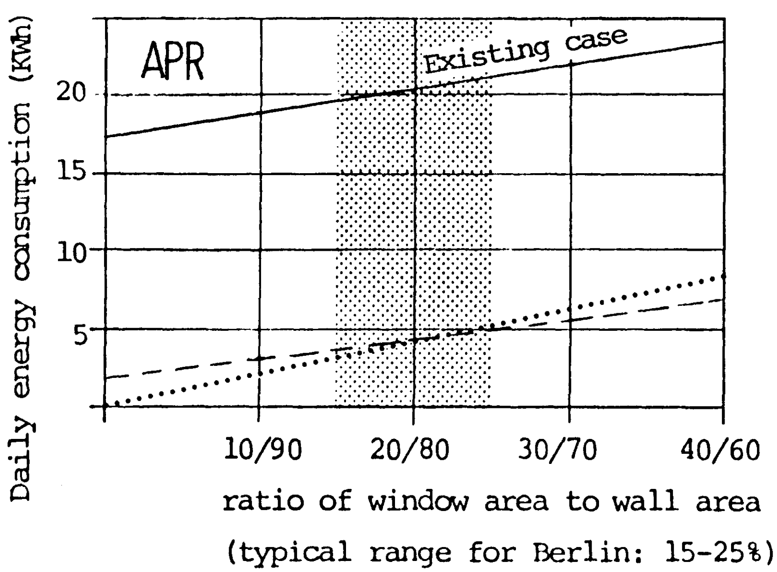
60% total solar transmission through the glazing
90% absorption inside the building
353 W/m^2 daily irradiation on a vertical north-facing surface



---- Redesign base-case, assuming:
k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.6 W/°Cm^2
infiltration-rate: 0.5/hr; no night insulation

-·-·- Redesign improved case, assuming:
k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.0 W/°Cm^2
infiltration-rate: 0.5/hr; with night insulation
-··- heat-exchanger with 50% heat recovery

...... Heat gains, assuming:
60% total solar transmission through the glazing
90% absorption inside the building
706 W/m^2 daily irradiation on a vertical north-facing surface



---- Redesign base-case, assuming:
k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.6 W/°Cm^2
infiltration-rate: 0.5/hr; no night insulation

-·-·- Redesign improved case, assuming:
k-value of wall : 0.5 W/°Cm^2
k-value of window: 1.0 W/°Cm^2
infiltration-rate: 0.5/hr; with night insulation
-··- heat-exchanger with 50% heat recovery

...... Heat gains, assuming:
60% total solar transmission through the glazing
90% absorption inside the building
984 W/m^2 daily irradiation on a vertical north-facing surface

Evaluation

In December the major reduction in heat losses was achieved by adding insulation to the thermally very poor wall (= 43% reduction), replacing the window glass by S.I.V.'s new product (= another 9% reduction), and cutting down the air change rate by half (= another 22% reduction). These improvements are considered as a first necessary step for insufficiently insulated buildings before passive means can be applied. Through all the monthly calculations these improvements are referred to as "Redesign base-case".

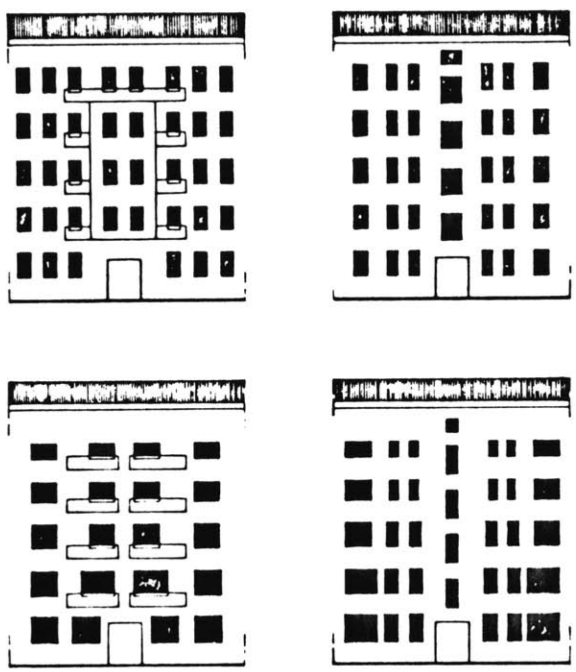
In a second step of further heat loss reductions some other common improvements are tested: 2,5cm of Styrofoam as night insulation are added (12 hours in use are assumed) The calculations show that their reducing effect is rather inimportant for the overall heat loss rate: savings between 1-2 KWh per day are gained throughout the winter months, not enough to consider their use in Berlin's tenement housing.

A slightly more effective reduction in heat losses was achieved by simulating the installment of a heat exchanger (in addition to the improvements of the redesign base-case) which would reduce the ventilation losses by 50%. Both tested improvements, therefore, would have a payback period which economically is not justifiable.

During the months November till March a daily net heating load between 5 KWh (Nov) and 12 KWh (Jan) has to be met by the auxiliary heating system - assuming the conditions of the redesign base-case and 25% window area.

Enlarging the north window areas as part of the redesign would lead to higher heat losses for this period, exept for November and February when heat loss through any amount of north window area is entirely compensated by solar gains through the same amount of window area. During these two months an enlargement in window area would not impair the overall energy consumption.

In the transition month March an enlargement of the northfacing window area would lead to a constantly increasing gain in solar energy.



If it were possible to glaze 100% of the north facade in March, almost all the daily heat losses could be replaced by daily solar heat gains from the diffuse radiation. More glass thus means more heat gain, contrary to the prevailing notion, that more glass means more heat losses.

In further design considerations this result might lead to "changeable facades", involving totally glazed north facades mostly covered in winter months with insulating panels which are then gradually removed as solar radiation levels and outdoor air temperatures increase.

Further improvements in glazing materials already demonstrated in industrial labs (6-7% more transmittance, 15% better k-value), promise that the beginning of similar effects can be moved to as late as November and as early as February.
In April and October all the heat losses through the building skin (Redesign Base Case) are equalized by incoming diffuse radiation. To achieve this the necessary daily radiation level on a vertical north-facing window has to be above 800-900 W/m^2 and outdoor temperatures should be at least 8-10°C.

CONCLUSION

There can be no doubt, that first of all conservation measures have to be taken to improve the existing thermally poor tenement housing. Its high energy consumption thereby will be reduced to a more acceptable level.
As long as the ratio of the wall area is within a range from 15% to 20% the major reductions can be achieved through insulating the walls. In comparison, an improvement on the window side leads to lesser reductions. Making the house air tighter and reducing thereby the infiltration rate is another effective possibility for saving heat.
More than any other measure taken to improve the thermal performance of passive systems, the control of the infiltration rate depends heavily on user participation, and is thereby hardly predictable.
This is especially true for the main heating season from December till February with the highest heating requirements of the year. Nevertheless, even during these cold months with lower radiation levels the solar contribution to lowering the heating load is remarkable. Naturally this effect is more obvious for the southfacing parts of an apartment than for the northfacing.
Dealing with the transition months April and October for the first time the northfacing windows contribute significantly to the overall solar heat gains: They are able to meet entirely the heat requirements of the northern half of the apartment.
Enlarging the northfacing window-area as a redesign measure does not entail a penalty during November and February because the increased heat losses through the window are exactly replaced by the also increased solar gains.
Assuming a free convective air flow through the open floor plan, heat which was generated by the sun in the southern half of an apartment can contribute towards heating the other half too.
The yearly heating period can be reduced by another two months, which than leaves only 3 months of the year for additional auxiliary heating.

APPENDIX

For West-Germany one may obtain weather data from:

Deutscher Wetterdienst
Meteorologisches Observatorium
Framredder 95
2000 Hamburg 65

Two publications by the German Weather Service are helpful to gain further detailed weather data:
"Die Klimaatlanten der deutschen Bundesländer"
and the
"Berichte des Deutschen Wetterdienstes."

Some other sources that might be contacted are

- Universities
- Meteorological Institutes
- Airports
- City-governments
- Private firms with collecter-test-facilities

For some bordering regions of West-Germany one might consult weather services of adjacent countries [53], [54].
Weather-related data are also available from the
World Meteorological Organization (WMO)
21 avenue Guiseppe Motta
Geneva, Switzerland

Denmark:	Meteorologisk Institute Gamle Havaele 22 2920 Charlottenlund
Netherlands:	Koninklijk Nederlands Meteorologisch Institut Utrechtsweg 297 De Bilt
France:	Météorologie Nationale 1 quai Branly 75 Paris 7^e
Switzerland:	Institute suisse de météorologie Krähbühlstrasse 58 8044 Zürich
Austria:	Zentralanstalt für Meteorologie und Geodynamik Hohe Warte 38 1190 Wien
German Democratic Republic:	Meteorologischer Dienst der DDR Ludenwalderstrasse 42-46 15 Potsdam 2

Daily Profile Solar Angles and Radiation

(by Chris Benton, 1978)

Program description:

Given base data, the TI-59 program calculates solar altitude, solar azimuth and angle of incidence to a specified plane. Hourly quantities of direct, diffuse and total radiation at the same plane are printed. Calculations are via ASHRAE procedures for incident radiation values.

Input data:

Sto 02 = Latitude of Berlin

Sto 03 = Longitude (use standard meridian to receive values for solar noon)

Sto 04 = Atmospheric clearance factor: 0.85

Sto 05 = Equation of time (0 for solar noon)

Sto 06 = Declination of particular month (ASHRAE chapter 26.2)

Sto 07 = Enter A (in W/m^2) converted from ASHRAE -table 1 in chapter 26.2

Sto 08 = Enter air mass correction from same ASHRAE table

Sto 09 = Enter C from same ASHRAE table

Sto 10 = Ground reflectance: 0.3

Sto 11 = Surface tilt (vertical = 90)

Sto 12 = Surface orientation (0 = South
+90 = East
-90 = West)

Hourly output data (in sequence) for the 21. of each month:

Altitude
Azimuth
Angle of incidence
Direct (beam) radiation (W/m^2)
Indirect (diffuse) radiation (W/m^2)
Total radiation (W/m^2)

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 -20. 06 1230. 07 0.142 08 0.058 09 0.3 10 90. 11 0. 12	8.00 1.13 -54.48 54.49 0.46 0.03 0.49	12.00 18.00 0.00 18.00 628.00 55.50 683.51 18.9%	16.00 1.13 54.48 54.49 0.46 0.03 0.49
5.00	9.00 8.02 -42.15 42.76 277.50 22.16 299.66 8.3%	13.00 16.82 14.72 22.21 592.50 51.90 644.40 17.8%	17.00
6.00	10.00 13.39 -28.88 31.59 482.29 41.01 523.29 14.5%	14.00 13.39 28.88 31.59 482.29 41.01 523.29 14.5%	18.00
7.00	11.00 16.82 -14.72 22.21 592.50 51.90 644.40 17.8%	15.00 8.02 42.15 42.76 277.50 22.16 299.66 8.3%	19.00

MONTH: JANUARY

TOTAL 3615. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 -10.8 06 1214.7 07 0.144 08 0.06 09 0.3 10 90. 11 0. 12	8.00 8.90 -59.44 59.84 204.51 25.32 229.84 4.8%	12.00 27.20 0.00 27.20 670.16 81.05 751.21 15.6%	16.00 8.90 59.44 59.84 204.51 25.32 229.84 4.8%
5.00	9.00 16.26 -46.35 48.49 409.10 50.00 459.10 9.6%	13.00 25.88 16.41 30.34 640.68 77.56 718.24 14.9%	17.00 0.51 71.60 71.60 0.00 0.00 0.00
6.00	10.00 22.09 -32.01 38.21 553.17 67.17 620.34 12,9%	14.00 22.09 32.01 38.21 553.17 67.17 620.34 12.9%	18.00
7.00 0.51 -71.60 71.60 0.00 0.00 0.00	11.00 25.88 -16.41 30.34 640.68 77.56 718.24 14.9%	15.00 16.26 46.35 48.49 409.10 50.00 459.10 9.6%	19.00

MONTH: FEBRUARY

TOTAL 4803. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 0. 06 1186.3 07 0.156 08 0.071 09 0.3 10 90. 11 0. 12	8.00 17.93 -65.54 66.80 239.35 56.08 295.43 5.8%	12.00 38.00 0.00 38.00 616.74 108.40 725.14 14.3%	16.00 17.93 65.54 66.80 239.35 56.08 295.43 5.8%
5.00	9.00 25.81 -51.76 56.14 392.65 78.54 471.19 9.3%	13.00 36.49 18.78 40.43 590.42 104.99 695.41 13.7%	17.00 9.17 78.08 78.23 77.26 26.54 103.80 2.0%
6.00	10.00 32.22 -36.23 46.97 513.58 94.92 608.50 12.0%	14.00 32.22 36.23 46.97 513.58 94.92 608.50 12.0%	18.00
7.00 9.17 -78.08 78.23 77.26 26.54 103.80 2.0%	11.00 36.49 -18.78 40.43 590.42 104.99 695.41 13.7%	15.00 25.81 51.76 56.14 392.65 78.54 471.19 9.3%	19.00
MONTH: MARCH			TOTAL 5069. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT	
52.	02
15.	03
0.85	04
0.	05
11.6	06
1135.8	07
0.18	08
0.097	09
0.3	10
90.	11
0.	12

8.00	27.39	-72.83	74.80	171.14	86.20	257.34	5.8%
12.00	49.60	0.00	49.60	494.00	135.12	629.12	14.0%
16.00	27.39	72.83	74.80	171.14	86.20	257.34	5.8%
5.00	0.14	-108.88	90.00	0.00	0.00	0.00	
9.00	35.80	-58.65	65.04	299.51	107.01	406.52	9.1%
13.00	47.82	22.18	51.55	470.85	131.91	602.76	13.5%
17.00	18.33	85.41	85.64	41.40	60.05	101.44	2.3%
6.00	9.12	-97.20	90.00	0.00	26.91	26.91	0.5%
10.00	42.90	-41.96	57.00	403.69	122.40	526.09	11.8%
14.00	42.90	41.96	57.00	403.69	122.40	526.09	11.8%
18.00	9.12	97.20	90.00	0.00	26.91	26.91	0.5%
7.00	18.33	-85.41	85.64	41.40	60.05	101.44	2.3%
11.00	47.82	-22.18	51.55	470.85	131.91	602.76	13.5%
15.00	35.80	58.65	65.04	299.51	107.01	406.52	9.1%
19.00	0.14	108.88	90.00	0.00	0.00	0.00	

MONTH: APRIL

TOTAL 4465. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT		
	52.	02
	15.	03
	0.85	04
	0.	05
	20.	06
	1104.25	07
	0.196	08
	0.121	09
	0.3	10
	90.	11
	0.	12

5.00	6.88	-113.90	90.00	0.00	17.66	17.66	0.4%
6.00	15.64	-102.63	90.00	0.00	54.01	54.01	1.4%
7.00	24.79	-91.19	90.00	0.00	83.24	83.24	2.1%
8.00	33.97	-78.90	80.81	105.53	107.38	212.91	5.4%
9.00	42.73	-64.77	71.76	220.11	126.88	346.99	8.8%
10.00	50.40	-47.49	64.49	313.48	141.36	454.84	11.6%
11.00	55.93	-25.73	59.69	373.89	150.32	524.21	13.3%
12.00	58.00	0.00	58.00	394.75	153.35	548.10	14.0%
13.00	55.93	25.73	59.69	373.89	150.32	524.21	13.3%
14.00	50.40	47.49	64.49	313.48	141.36	454.84	11.6%
15.00	42.73	64.77	71.76	220.11	126.88	346.99	8.8%
16.00	33.97	78.90	80.81	105.53	107.38	212.91	5.4%
17.00	24.79	91.19	90.00	0.00	83.24	83.24	2.1%
18.00	15.64	102.63	90.00	0.00	54.01	54.01	1.4%
19.00	6.88	113.90	90.00	0.00	17.66	17.66	0.4%
TOTAL	3928.						100%

MONTH: MAY

INPUT	
52.	02
15.	03
0.85	04
0.	05
23.45	06
1088.5	07
0.205	08
0.134	09
0.3	10
90.	11
0.	12

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

5.00	9.64	-116.00	90.00	0.00	30.51	30.51	0.8%
6.00	18.28	-104.95	90.00	0.00	64.55	64.55	1.7%
7.00	27.37	-93.74	90.00	0.00	92.45	92.45	2.5%
8.00	36.58	-81.66	63.31	76.39	115.77	192.17	5.2%
9.00	45.48	-67.69	74.56	184.74	134.67	319.41	8.6%
10.00	53.39	-50.28	67.60	273.11	148.72	421.84	11.3%
11.00	59.22	-27.65	63.04	330.37	157.41	487.78	13.1%
12.00	61.45	0.00	61.45	350.15	160.35	510.49	13.7%
13.00	59.22	27.65	63.04	330.37	157.41	487.78	13.1%
14.00	53.39	50.28	67.60	273.11	148.72	421.84	11.3%
15.00	45.48	67.69	74.56	184.74	134.67	319.41	8.6%
16.00	36.58	81.66	63.31	76.39	115.77	192.17	5.2%
17.00	27.37	93.74	90.00	0.00	92.45	92.45	2.5%
18.00	18.28	104.95	90.00	0.00	64.55	64.55	1.7%
19.00	9.64	116.00	90.00	0.00	30.51	30.51	0.8%
TOTAL						3720.	100%

MONTH: JUNE

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 20.6 06 1085.3 07 0.207 08 0.136 09 0.3 10 90. 11 0. 12	8.00 34.43 -79.37 81.25 97.36 110.80 208.16 5.4%	12.00 58.60 0.00 58.60 377.13 156.66 533.79 13.9%	16.00 34.43 79.37 81.25 97.36 110.80 208.16 5.4%
5.00 7.36 -114.26 90.00 0.00 19.73 19.73 0.5%	9.00 43.22 -65.26 72.24 207.94 130.31 338.25 8.8%	13.00 56.50 26.04 60.27 356.89 153.65 510.54 13.2%	17.00 25.24 91.63 90.00 0.00 86.50 86.50 2.2%
6.00 16.10 -103.03 90.00 0.00 56.84 56.84 1.5%	10.00 50.93 -47.95 65.03 298.31 144.75 443.06 11.5%	14.00 50.93 47.95 65.03 298.31 144.75 443.06 11.5%	18.00 16.10 103.03 90.00 0.00 56.84 56.84 1.5%
7.00 25.24 -91.63 90.00 0.00 86.50 86.50 2.2%	11.00 56.50 -26.04 60.27 356.89 153.65 510.54 13.2%	15.00 43.22 65.26 72.24 207.94 130.31 338.25 8.8%	19.00 7.36 114.26 90.00 0.00 19.73 19.73 0.5%
MONTH: JULY			TOTAL 3853. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT	
52.	02
15.	03
0.85	04
0.	05
12.3	06
1107.5	07
0.201	08
0.122	09
0.3	10
90.	11
0.	12

8.00	27.95	-73.30	75.30	155.59	91.71	247.30	5.8%
12.00	50.30	0.00	50.30	463.07	141.15	604.23	14.0%
16.00	27.95	73.30	75.30	155.59	91.71	247.30	5.8%
5.00	0.70	-109.30	90.00	0.00	0.00	0.00	
9.00	36.39	-59.11	65.59	277.23	112.89	390.12	9.1%
13.00	48.50	22.43	52.23	440.89	137.94	578.83	13.5%
17.00	18.88	85.87	86.09	34.45	64.66	99.11	2.3%
6.00	9.66	-97.65	90.00	0.00	29.70	29.70	0.7%
10.00	43.54	-42.37	57.61	376.61	128.41	505.01	11.7%
14.00	43.54	42.37	57.61	376.61	128.41	505.01	11.7%
18.00	9.66	97.65	90.00	0.00	29.70	29.70	0.7%
7.00	18.88	-85.87	86.09	34.45	64.66	99.11	2.3%
11.00	48.50	-22.43	52.23	440.89	137.94	578.83	13.5%
15.00	36.39	59.11	65.59	277.23	112.89	390.12	9.1%
19.00	0.70	109.30	90.00	0.00	0.00	0.00	

MONTH: AUGUST

TOTAL	4300.	100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 0. 06 1151.6 07 0.177 08 0.092 09 0.3 10 90. 11 0. 12	8.00 17.93 -65.54 66.80 217.02 58.37 275.40 5.8%	12.00 38.00 0.00 38.00 578.62 111.72 690.34 14.4%	16.00 17.93 65.54 66.80 217.02 58.37 275.40 5.8%
5.00	9.00 25.81 -51.76 56.14 363.21 81.55 444.76 9.3%	13.00 36.49 18.78 40.43 553.27 108.31 661.57 13.8%	17.00 9.17 78.08 78.23 65.74 26.98 92.72 1.9%
6.00	10.00 32.22 -36.23 46.97 479.30 98.17 577.47 12.0%	14.00 32.22 36.23 46.97 479.30 98.17 577.47 12.0%	18.00
7.00 9.17 -78.08 78.23 65.74 26.98 92.72 1.9%	11.00 36.49 -18.78 40.43 553.27 108.31 661.57 13.8%	15.00 25.81 51.76 56.14 363.21 81.55 444.76 9.3%	19.00

MONTH: SEPTEMBER

TOTAL 4788. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL..
(Atmospheric clearance factor: 0.85)

INPUT	
52.	02
15.	03
0.85	04
0.	05
-10.5	06
1192.6	07
0.16	08
0.073	09
0.3	10
90.	11
0.	12

	8.00 9.15 -59.60 60.03 185.23 26.44 211.67 4.6%	12.00 27.50 0.00 27.50 635.85 83.66 719.52 15.7%	16.00 9.15 59.60 60.03 185.23 26.44 211.67 4.6%
5.00	9.00 16.53 -46.49 48.69 381.25 52.05 433.31 9.5%	13.00 26.18 16.47 30.61 607.01 80.14 687.15 15.0%	17.00 0.75 71.77 71.78 0.00 0.00 0.00
6.00	10.00 22.37 -32.12 38.45 521.48 69.61 591.09 12.9%	14.00 22.37 32.12 38.45 521.48 69.61 591.09 12.9%	18.00
7.00 0.75 -71.77 71.78 0.00 0.00 0.00	11.00 26.18 -16.47 30.61 607.01 80.14 687.15 15.0%	15.00 16.53 46.49 48.69 381.25 52.05 433.31 9.5%	19.00

MONTH: OCTOBER

TOTAL 4563. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 -19.8 06 1121. 07 0.149 08 0.063 09 0.3 10 90. 11 0. 12	8.00 1.30 -54.59 54.60 0.78 0.06 0.84	12.00 18.20 0.00 18.20 561.76 51.92 613.69 18.9%	16.00 1.30 54.59 54.60 0.78 0.06 0.84
5.00	9.00 8.20 -42.24 42.88 245.73 20.91 266.64 8.2%	13.00 17.01 14.75 22.38 529.51 48.58 578.09 17.8%	17.00
6.00	10.00 13.58 -28.94 31.72 429.63 38.47 468.09 14.5%	14.00 13.58 28.94 31.72 429.63 38.47 468.09 14.5%	18.00
7.00	11.00 17.01 -14.75 22.38 529.51 48.58 578.09 17.8%	15.00 8.20 42.24 42.88 245.73 20.91 266.64 8.2%	19.00
MONTH: NOVEMBER			TOTAL 3287. 100%

Daily incident radiation on a vertical southfacing surface under clear-day-conditions for 52° NL (Atmospheric clearance factor: 0.85)

INPUT 52. 02 15. 03 0.85 04 0. 05 -23.5 06 1233.6 07 0.142 08 0.057 09 0.3 10 90. 11 0. 12	8.00	12.00 14.50 0.00 14.50 575.74 44.37 620.11 21.0%	16.00
5.00	9.00 4.88 -40.60 40.84 149.27 9.83 159.10 5.3%	13.00 13.36 14.12 19.35 535.23 40.69 575.92 19.5%	17.00
6.00	10.00 10.06 -27.76 29.39 405.37 29.43 434.80 14.7%	14.00 10.06 27.76 29.39 405.37 29.43 434.80 14.7%	18.00
7.00	11.00 13.36 -14.12 19.35 535.23 40.69 575.92 19.5%	15.00 4.88 40.60 40.84 149.27 9.83 159.10 5.3%	19.00

MONTH: DECEMBER

TOTAL 2956. 100%

Average Daily Radiation III (by James Rosen 1980)

Program description:

Given a data base, this program calculates the average daily insolation striking a surface of any orientation. The daily radiation is broken down into its beam, diffuse and reflected components, in order to facilitate determing the quantity transmitted through a glazing. This program follows the method outlined by S.A. Klein "Calculation of Monthly Average Insolation on tilted Surfaces", Solar Energy, Vol.19, No.4, 1977.

Input data :

- Surface tilt: (90° =vertical)
- Absolute Value of azimuth angle: (o = South, 90 = East or West, 180 = North)
- Ground reflectance: 0.3 is assumed
- Latitude of location: 52° North Latitude
- Number of month (Jan = 1, Feb = 2,...)
- Monthly average daily total global radiation on a horizontal surface from Fig. 28, page 49. (in W/m^2)

Average daily insolation (beam, diffuse, reflected, total) on southfacing surfaces (Berlin-Dahlem)

	1. 90. 0. 0.3 52. 602.	MON TILT AZIM REFL LAT AVE	2. 90. 0. 0.3 52. 1146.	MON TILT AZIM REFL LAT AVE	3. 90. 0. 0.3 52. 2361.	MON TILT AZIM REFL LAT AVE	4. 90. 0. 0.3 52. 3349.	MON TILT AZIM REFL LAT AVE
90° TILT	834.4 205.2 90.3 1129.9	BEAM DIFF REFL TOTL	1081.9 368.7 171.9 1622.6	BEAM DIFF REFL TOTL	1490.0 655.7 354.2 2499.9	BEAM DIFF REFL TOTL	1087.0 935.5 502.4 2524.8	BEAM DIFF REFL TOTL
60° TILT	818.4 307.8 45.1 1171.4	BEAM DIFF REFL TOTL	1141.2 553.1 85.9 1780.3	BEAM DIFF REFL TOTL	1815.2 983.5 177.1 2975.8	BEAM DIFF REFL TOTL	1655.9 1403.2 251.2 3310.3	BEAM DIFF REFL TOTL
45° TILT	725.5 350.3 26.4 1102.2	BEAM DIFF REFL TOTL	1053.9 629.5 50.3 1733.7	BEAM DIFF REFL TOTL	1795.8 1119.3 103.7 3018.9	BEAM DIFF REFL TOTL	1785.5 1597.0 147.1 3529.7	BEAM DIFF REFL TOTL
30° TILT	583.1 382.9 12.1 978.1	BEAM DIFF REFL TOTL	894.7 688.1 23.0 1605.9	BEAM DIFF REFL TOTL	1654.0 1223.5 47.4 2925.0	BEAM DIFF REFL TOTL	1797.3 1745.7 67.3 3610.3	BEAM DIFF REFL TOTL

Average daily insolation (beam, diffuse, reflected, total) on southfacing surfaces (Berlin-Dahlem)

	5.	MON	6.	MON	7.	MON	8.	MON
	90.	TILT	90.	TILT	90.	TILT	90.	TILT
	0.	AZIM	0.	AZIM	0.	AZIM	0.	AZIM
	0.3	REFL	0.3	REFL	0.3	REFL	0.3	REFL
	52.	LAT	52.	LAT	52.	LAT	52.	LAT
	4692.	AVE	5317.	AVE	5158.	AVE	4464.	AVE
90° TILT	1018.3	BEAM	929.9	BEAM	1041.3	BEAM	1454.7	BEAM
	1170.0	DIFF	1264.1	DIFF	1209.2	DIFF	1018.8	DIFF
	703.8	REFL	797.6	REFL	773.7	REFL	669.6	REFL
	2892.0	TOTL	2991.5	TOTL	3024.2	TOTL	3143.1	TOTL
60° TILT	1940.3	BEAM	2008.0	BEAM	2109.2	BEAM	2404.4	BEAM
	1754.9	DIFF	1896.1	DIFF	1813.8	DIFF	1528.2	DIFF
	351.9	REFL	398.8	REFL	386.8	REFL	334.8	REFL
	4047.1	TOTL	4302.8	TOTL	4309.9	TOTL	4267.4	TOTL
45° TILT	2247.5	BEAM	2408.1	BEAM	2486.1	BEAM	2665.3	BEAM
	1997.2	DIFF	2157.9	DIFF	2064.3	DIFF	1739.2	DIFF
	206.1	REFL	233.6	REFL	226.6	REFL	196.1	REFL
	4450.9	TOTL	4799.6	TOTL	4777.0	TOTL	4600.6	TOTL
30° TILT	2420.0	BEAM	2673.9	BEAM	2718.8	BEAM	2755.2	BEAM
	2183.2	DIFF	2358.8	DIFF	2256.4	DIFF	1901.1	DIFF
	94.3	REFL	106.9	REFL	103.7	REFL	89.7	REFL
	4697.4	TOTL	5139.5	TOTL	5078.9	TOTL	4746.1	TOTL

Average daily insolation (beam, diffuse, reflected, total) on southfacing surfaces (Berlin-Dahlem)

	9.	MON	10.	MON	11.	MON	12.	MON
	90.	TILT	90.	TILT	90.	TILT	90.	TILT
	0.	AZIM	0.	AZIM	0.	AZIM	0.	AZIM
	0.3	REFL	0.3	REFL	0.3	REFL	0.3	REFL
	52.	LAT	52.	LAT	52.	LAT	52.	LAT
	3063.	AVE	1609.	AVE	733.	AVE	439.	AVE
90° TILT	1737.6	BEAM	1452.8	BEAM	903.8	BEAM	639.9	BEAM
	756.0	DIFF	467.3	DIFF	245.9	DIFF	157.3	DIFF
	459.5	REFL	241.4	REFL	110.0	REFL	65.9	REFL
	2953.0	TOTL	2161.5	TOTL	1259.7	TOTL	863.1	TOTL
60° TILT	2278.5	BEAM	1595.4	BEAM	903.3	BEAM	616.4	BEAM
	1134.0	DIFF	701.0	DIFF	368.9	DIFF	235.9	DIFF
	229.7	REFL	120.7	REFL	55.0	REFL	32.9	REFL
	3642.2	TOTL	2417.0	TOTL	1327.2	TOTL	885.3	TOTL
45° TILT	2323.3	BEAM	1504.2	BEAM	809.6	BEAM	540.5	BEAM
	1290.6	DIFF	797.7	DIFF	419.9	DIFF	268.5	DIFF
	134.6	REFL	70.7	REFL	32.2	REFL	19.3	REFL
	3748.4	TOTL	2372.6	TOTL	1261.6	TOTL	828.3	TOTL
30° TILT	2210.1	BEAM	1310.4	BEAM	660.7	BEAM	427.7	BEAM
	1410.7	DIFF	872.0	DIFF	458.9	DIFF	293.5	DIFF
	61.6	REFL	32.3	REFL	14.7	REFL	8.8	REFL
	3682.3	TOTL	2214.8	TOTL	1134.4	TOTL	730.0	TOTL

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